THE PHYSIOGRAPHY OF THE COX RIVER BASIN.

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(Plates xix-xx, and seventeen Text-figures.)

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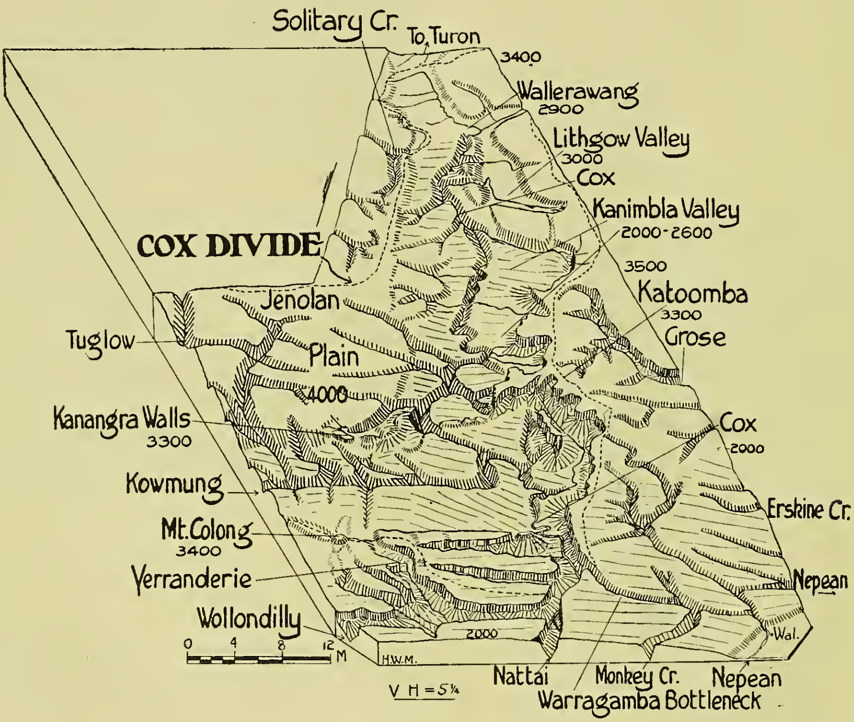
Introduction.

This paper treats of the rough Blue Mountain Plateau, a good deal of which is very little known. It commences with an examination of topographic features, and the influence of rock structure on these is traced. It is then possible to divide the area into a number of small parts according to form and development of surface features. The evolution of each part is traced, and the parts correlated. In this way the earth movements which have affected the area are discovered and explained. In the light of the knowledge thus obtained the development of the stream system is traced, and the past physiographic history of the area is outlined.

The research work which this paper describes was undertaken during 1926 under the supervision of Professor Griffith Taylor, to whom my thanks are due

for his great interest in the work, and for many suggestions of his which are embodied in this paper. Much of its merit is due to him, and to his continual encouragement. Next, I have to thank Miss W. Riley, of Leura, for most of the printing on the diagrams. Messrs. H. C. Allen, B.Sc., and C. H. Black, B.Sc., assisted in the work on Jamieson's Valley in very bad weather, and I owe a great deal to them. The Water Conservation and Irrigation Commission has also supplied a valuable map and other information.



Text-Fig. 1.—The Cox River Basin.
Block Diagram of the Area. This summarizes the topography. The plateau masses are trenched by narrow gorges and valleys on the south and east, whilst broad, mature valleys, which are now being trenched by the streams, are found in the centre and north of the area. The great Kowmung Canyon is very striking.

My very sincere thanks are also due to many residents of the area who assisted me in a variety of ways. I would like to mention particularly Messrs. Bulkeley (Wallerawang); Kirby and Carlon (Megalong); Maxwell and Kill (Kedumba or Jamieson's Creek); and James and Kerswell (Lower Burragorang); together with their wives and families. Many others have also earned my hearty thanks, and I would pay a tribute to their kindness and helpfulness, without which it would have been impossible to examine all the area which is here described.

Area dealt with.—In this paper, the Cox River Basin is taken to include that area of country drained by the Cox and Kowmung Rivers and their tributaries, together with the Warragamba and Lower Wollondilly Rivers. The latter streams are included because the problems associated with them are intimately related

to the problems presented by the Cox. This embraces an area of some 1,600 square miles.

Previous work and literature.—The area has not been treated previously, as a whole, in any detail. Mr. Andrews and Professor Griffith Taylor have written valuable papers on the general physiography of the area, and intensive research tends to prove many of their theories. The geology of the country adjacent to the Main Western Railway and the Lithgow Coalfield is fairly well known, but the geology of the rough Kowmung, Kanangra and Jenolan River basins, and Mt. Mouin district has not been studied. Some observations on this phase of the subject are embodied in the paper.

General considerations.—The Cox River area includes some of the wildest and most broken country in this State; and has, since the earliest days of white settlement, proved to be a great obstacle in the way of free communication between Sydney and the interior—not so much on account of the altitude involved, but because of the profound recent dissection of a moderately uplifted surface. The great gorges which the main streams have cut have, in general, a north-south trend across the radial lines of communication from the Sydney Basin, and only where persistent east-west ridges occur, as in the case of the Glenbrook-Clarence watershed, is the relatively easy construction of roads and railways possible.

Classification of Regions.

A study of the Block Diagram (Text-fig. 1) will show that the area includes a number of dissimilar physiographic types. The streams of the Upper Cox flow to the east in broad, flat valleys which have, however, a general outlet to the west, into the Macquarie basin. The Middle Cox basin consists of a series of broad, flat valleys which have been trenched by deep juvenile gorges; whilst the Lower Cox and its associated streams flow from the wide valleys into deep, narrow trenches, finally debouching on the plains of the Sydney Basin. Thus the area appears to fall into a number of well-defined natural regions, which are determined mainly by differences of elevation. There are six of these regions, which vary notably from one another, and whose characteristics will now be described.

(i). *The Blue Plateau.*—In this paper, the term "Blue Plateau" will be used in a restricted sense. The plateau extends from the Hunter River Valley in the north to Lake George in the south and can, in a general sense, be described as a topographic unit and have the name "Blue Plateau" applied to it. Here, however, the term will be used to designate that elevated sandstone block which in parts rises to 3,500 feet above sea-level, and occupies all of the northern and eastern parts of the area, together with the lower warped country leading up to it. This region has three well-marked subdivisions, viz.. the lower or Mulgoa "step", extending from Glenbrook to the south of The Oaks; the King's Tableland "step", extending from Hazelbrook in the north away beyond Oakdale in the south, including the country to the east of Jamieson's Creek and the Lower Wollondilly; and the main plateau, varying from 3,000 to 3,500 feet in elevation, and extending westwards from a line joining Katoomba with Mounts Hay, Tomah, Wilson and Irvine. Between these steps are stretches of uniformly-sloping land. This plateau is essentially a recently-warped peneplain, and is deeply dissected in parts.

(ii). *Jenolan Plain or Plateau.*—This region consists mainly of soft Silurian rocks. It is about 700 feet higher than the main mass of the Blue Plateau, whose average elevation is about 3,300 feet. The Jenolan Plateau extends vertically from

3,700 to 4,400 feet above sea-level, having an average elevation slightly in excess of 4,000 feet. Its surface is generally very level, but is trenched in the east and north-east by deep gorges. This plateau extends from Sunny Corner south-eastwards to Kanangra Walls, and westwards to the Stony Ridges near Bathurst.

(iii). *Wallerawang and Lithgow Valley Levels.*—The area of flat late mature valleys at an elevation of 3,100 feet centring on Wallerawang comes under this heading, and includes the Lithgow, Portland, Wallerawang and Solitary Creek Valleys, together with similar higher valleys to the south, on Boyd Creek and the Upper Tuglow, for example. It will be seen, from the outset, that these valleys are cut in a variety of rocks.

(iv). *Kanimbla and Megalong Valleys.*—The middle course of the Cox, between Lett River and the Narrow Neck-Gangerang Range line, is marked by a great series of upland valleys. These occur at elevations varying from 1,900 to 2,500 feet, having an average elevation of 2,200 feet. The valley floor is geologically varied, consisting of granite, conglomerate, sandstone, and certain slates, etc. The valley itself contains some alluvial deposits to the north of the Cox, and is, physiographically, of great interest. On the eastern margin, the river leaves the valley by a great canyon which is, for nineteen miles, nowhere less than 2,000 feet deep.

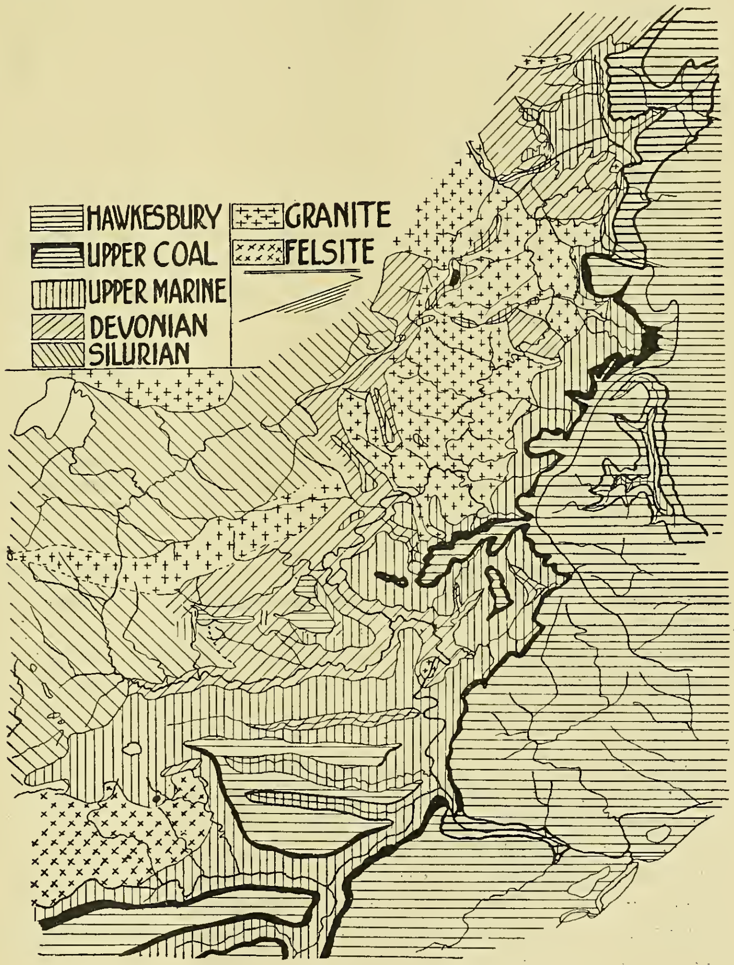
(v). *Jamieson's Valley and the Kowmung Basin.*—Jamieson's Valley and the Kowmung Basin form a great oval-shaped valley, which is divided into two parts by the Cox River. The river does not, however, destroy the unity of the feature. The lower part of Jamieson's Valley is only 500 feet above sea-level, but a steadily-rising warped surface extends to the west, south-west and south of the small stream flats, rising to 2,300 feet on the Megalong level at Megalong Gap; and to 2,800 feet at Bindook Pass, on the southern divide of the Kowmung. The uniform warped valley floor is trenched by the Cox and Kowmung Rivers. The warping affected the mouth of Jamieson's Creek in a manner which will be discussed later.

(vi). *The Monadnocks.*—Rising above the respective surfaces of the plateaux are a number of monadnocks and residuals. These may be classed under two headings—the basalt residuals and the quartzite blocks. The former occur mainly along the southern divides of the Kowmung, and include Mounts Werong, Colong and Shivering, South Peak (Yerranderie), Harvey's Mount and a large area around Shooter's Hill. The old quartzite peaks are Mounts Walker, Flaherty, Bindo, Lambie and the Gangerang Range. The former appear to be relics of an ancient peneplain, but the latter are monadnocks that have existed through long periods of geological time on account of their great resistance to erosion. They are discussed more fully in other parts of the paper.

Geology of the Area.

Main Structural Features.—The rocks of the area are divisible into two main classes, namely, (i) Mesozoic and Upper Palaeozoic and (ii) Lower Palaeozoic. The former occupy the northern and eastern parts of the area; the latter occur in the centre, south-west and west. The Triassic and Permian beds (Hawkesbury and Narrabeen Series, Upper Coal Measures and Upper Marine Series) rest unconformably upon the older strata, and there is a definite line of demarcation between the present outcrops of the two. This line runs, roughly, along the Kowmung Valley, across the Cox, and on the northern side of Kanimbla Valley. The area to the west of the line would thus appear to have had a predominantly

upward movement since Devonian times, whilst the country to the north and east would appear to have been an area of relative depression. Thus some of the earth movements which are postulated in this paper appear to be renewals of these ancient earth movements, as the south-west (Jenolan Plateau) has undergone greater recent elevation than the remainder of the area.



Text-fig. 2.—Geology of the Cox Basin.
The eastern and north-eastern parts are very much younger, geologically, than the western portion. The former represent the old regions of relative depression, whilst the latter represent areas of long-continued relative uplift.

The geological structure is thus readily understood (Text-fig. 2). Various outliers of the newer rocks are found on the older, higher rocks of the Jenolan Plateau; and these shed light, not only on the past geological history of the area, but also upon recent warping movements that have affected it. Two groups of out-

liers may be particularly noted—those along and adjacent to the Main Divide between Rydal and Jenolan, and those to the east of Kanangra Creek.

The first group consists of a series of outcrops strung out along the Main Divide between Rydal and Hampton, along some of the ridges running north and south from the Divide, the most notable being between Lowther and Hartley.

The relics belong to the Upper Marine Series, and consist mainly of sandstone and conglomerate. They rise from 3,100 feet near Rydal to 3,950 feet three miles to the north of Hampton, and 4,200 feet about three miles to the south-east of Jenolan Caves. At Hartley these rocks are found as low as 2,400 feet, but they rise 1,400 feet to Hampton, which is twelve miles distant at 3,800 feet.

The most interesting member of this group is that outlier which is found three miles to the north of Hampton. It stretches for two miles along the Main Divide, and attains a maximum thickness of 350 feet. It consists of conglomerate, shale, sandstone and, at the top, a bed of grey shale containing a six-inch band of coal. The latter is found right on the crest of the ridge, 3,950 feet above sea-level. The highest outcrop of coal on the western coalfield is at 3,200 feet at Piper's Flat, so there is a difference in elevation between the two of the order of 750 feet. This represents the extra amount of elevation which the Hampton beds have suffered compared to the corresponding rocks of the main Blue Plateau around Wallerawang; it is also equal to the difference in elevation between the Blue and Jenolan Plateaux.

Warping of the country between Hartley and Hampton must certainly have taken place unless one is prepared to assume that the conglomerate beds could have been laid down at and along the present slope, which is approximately 120 feet per mile.

The second series of outliers occurs to the east of Kanangra Creek, at Kanangra Walls and along the Gangerang Range. The newer sandstone is horizontal, and rests unconformably upon the older folded beds. Kanangra Walls are formed by the weathering of this rock along a major joint plane. The sandstone, whose upper surface is at 3,300 feet, attains a maximum thickness of 250 feet, and extends northwards along the eastern side of the Gangerang Range, appearing as a broken bench on the side of the high quartzite residual, which rises to 3,700 feet.

The age of this sandstone is doubtful. On the Geological Map of N.S.W., 1914, it is marked as belonging to the Upper Coal Measures. It extends at the 3,300 feet level along Gangerang Range, and appears to correspond to the Hawkesbury Series on Narrow Neck, Katoomba, at 3,400 feet. The presence of a coal band and the reputed occurrence of *Glossopteris* indicate that it does not belong to the Hawkesbury Series. The difference of elevation of 600 feet between this and the Hampton rocks may be remarked on as a sign of differential uplift.

Ancient Ranges and Peneplains.—From very early times the crust of the earth in this area has been in a state of unrest. The Silurian and Devonian beds are unconformable, and have been greatly crushed and folded. Since the close of the Carboniferous there has been relatively little folding, the earth movements having been more of a vertical character.

The geological history of the area opens with the Silurian sedimentation, when an extensive series of limestones, shales and interbedded volcanics, with subsequently-metamorphosed slates, was formed. A period of uplift and erosion was followed by further downthrust and sedimentation in the Devonian period.

The Devonian beds are now of a predominantly metamorphic character, consisting of quartzites, slates, shales, and intrusive porphyries.

At the close of the Devonian there was a great period of mountain-building, accompanied by the intrusion of a batholith of granite, quartz-porphyry dykes, and regional metamorphism. The country was intensely folded into a series of symmetrical synclines and anticlines, the relics of folding being still plainly visible. With the movement of uplift dominant, the land was kept above the sea, and a great cycle of erosion resulted in the reduction of the folds, and the formation of a peneplain. So great was the amount of erosion, that areas of the intruded granite were exposed. The harder rocks, such as Gangerang and Mt. Walker, persisted as peaks, up to 2,000 feet above the softer rocks of the peneplain, which formed gently-rolling plains. Some of the peaks exist at the present time.

At the close of the Carboniferous, a downward movement of the land interrupted the cycle of erosion. This movement was more intense in the east, and hardly affected the western part of the area. The Upper Marine beds and Upper Coal Measures were laid down unconformably on the upturned eroded edges of the slates, and quartzites, and on the granites. Until the close of the Triassic, the eastern part of the area continued to be depressed, but the western part appears to have been lifted above the sea at the close of the Permian. Since the deposition of the Hawkesbury, Narrabeen and Wianamatta beds—the latter only occurring on the eastern margin of the area—the major movement has been one of uplift. The earliest uplifts have all been obscured by those coming subsequently, and it is not until the period of basalt flows, probably later than Middle Tertiary, that we get a distinctive peneplain preserved. This is now represented mainly by isolated basalt areas and caps, a few of which, e.g., Mounts Colong, Shivering, Werong, Clarence, and the country near Shooter's Hill, are found in this area.

The great Tertiary Peneplain, which now forms the plateau surface, was probably formed in the latter part of the Tertiary period. The history of the land surface subsequent to this peneplanation, is most readily traced by physiographic methods.

The Rocks, and their Resistance to Erosion.—Reviewing the rock structures of the area, one is struck by the great resistance to erosion shown by the majority of the rock types. The younger sedimentary rocks—Triassic and Permian—are here near their western limits, and so consist mainly of sandstones, grits and conglomerates. The Hawkesbury Sandstone and Narrabeen beds are here practically all sandstone and grit, with only thin bands of shale. In general the Upper Coal Measures are soft, consisting of shales and crumbling sandstones, as in Jamieson's Valley and around Lithgow. Nearer their periphery they, too, are very hard. To the north of Piper's Flat the surface of the Blue Plateau is of hard Coal Measure sandstone (containing *Glossopteris*). On Mt. Mouin, and the ridge to the south-west of Yerranderie, these series consist mainly of resistant grits. At Wallerawang and Marangaroo also the basal beds—the Marangaroo Conglomerate—are very hard, forming cliffs where softer shale bands are cut away from beneath them.

The Upper Marine beds are also, in general, very resistant to weathering in such places as the Kanimbla and Wallerawang districts, where conglomerate and sandstone are predominant. To the east, as in Jamieson's Valley, a considerable thickness of shale and tuff also occurs. The basal deposits often contain small

deposits of alum. In parts, as in Megalong, there are bands of pebbles in a crumbly matrix, in which this alum is found. On the whole, the Upper Marine Series is very resistant to erosion in the west and south, and moderately resistant in the north-east.

The older rocks are principally igneous and metamorphic. Of these, the Devonian slates and quartzites are uniformly hard, whilst the Silurian slates and shales are much softer. One particular bed of the Devonian series, a white glassy quartzite which occurs on Gangerang Range and Mt. Walker, is particularly resistant. Practically the only natural means of disintegration is by the freezing of water in joint and bedding planes, which splits the rock up into cubes, with edge up to a foot, and which litter the mountain sides. The Devonian slates, too, are hard. On Breakfast Creek, for example, there has been no appreciable differential erosion in the slates and quartzites. The Silurian slates and shales are soft, giving a subdued topography, as on the uplands near Jenolan Caves, and forming characteristic saddle ridges as on the Kowmung-Wollondilly divide. The roots of falling trees, blown over by the wind, tear great holes in these rocks, which are generally strongly jointed and laminated. Despite the softness of its rock types, the Jenolan Plateau stands up as a high block, and so cannot be a mesa, or relic of a separate peneplanation older than that of the Blue Plateau.

The granites of the Cox Valley vary in hardness from place to place, but are generally not very resistant to erosion, on account of their susceptibility to chemical weathering. Where caps of Upper Marine sandstone occur in the valley, hills are found; but where the sandstone has been worn away, the granite is quickly eaten down, forming typical rolling hills. Above Galong Creek (Megalong Valley) for instance, the Cox is entrenched in undulating granite hills. Below this stream it flows into an extremely steep-sided ravine of Devonian strata. A small boss of granite is exposed on the Lower Cox below Jamieson's Creek.

The rocks can thus be classified in descending order of resistance to erosion as follows:—

i. Devonian quartzite and indurated conglomerate (latter on Jamieson's Creek). Basalt caps.
ii. Hawkesbury and Narrabeen sandstones; Upper Marine sandstones and conglomerates; some Upper Coal Measure sandstone.
iii. Devonian slates and intrusive porphyries.
iv. Granites, in general.
v. Silurian slates, shales, etc., in general.
vi. Upper Coal Measures; interstratified shales in the Upper Marine, Hawkesbury, Narrabeen, and Devonian Series.

Only the last two types are distinctly soft. It will be seen that the great mass of soft rocks on Jenolan Plateau lies away from the great Cox and Kowmung Valleys, which have been cut in almost uniformly hard rocks. The effect of this has been to reduce differential erosion to a minimum in the formation of the broad valleys.

Dominant Physiographic Features.

Blue (Mt.) and Jenolan Plateaux.—The Blue Plateau has been recognized by geographers and physiographers as part of an uplifted and dissected peneplain. Mr. Andrews originally regarded the Jenolan Plain as a relic of a more ancient cycle of erosion than that which formed the Blue Plateau (Geography of Blue

Mts.), but has since modified his views on the subject in general. He says (Geog. Unity of Eastern Australia, pp. 433-434): "It would appear, in fact, that wherever in Eastern Australia two unreduced plateau masses exist side by side at variable altitudes, a fault or sharp fold separates them". And again, "The same horst (i.e., west of Burragorang) exceeds 4,000 feet a few miles east of Bathurst, and the Bathurst Plains (2,500 feet) appear to be a senkungsfeld dropped between Orange and the Sunny Corner Highlands". There appears to be strong field evidence in support of these views.

The peneplain as an Australian feature is discussed by Dr. Fenner (Physiography of Werribee Area, p. 203, et seq.). He, in common with many other writers, whom he quotes, holds that the Tertiary peneplain is the dominant feature of the Australian highlands. The uplifted and dissected peneplain is represented in this area by the Blue and Jenolan Plateaux.

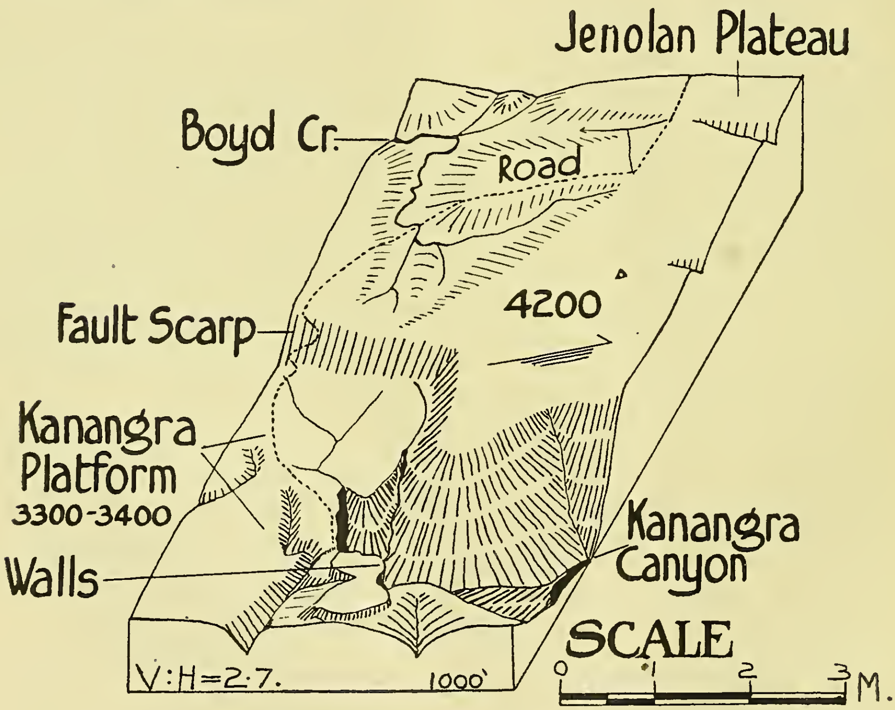
There are two main lines of evidence which seem to indicate that these two surfaces belong to the same cycle. Firstly, there is the relative hardness of the two masses. The surface of the Blue Plateau is composed of hard sandstones, but the Jenolan Plain is mainly composed of soft shales and slates. The presence of these rocks has resulted in very subdued topography in regions as yet unaffected by headward erosion caused by the upwarping of the plateau, the country around Hampton being typical of this. If the Jenolan Plain were a mesa, or relic of a one-time complete peneplain, one would expect the rocks of which it is composed to be hard and resistant to erosion. This, however, is not the case. There is evidence, both geological and physiographic, of recent differential uplift of the Jenolan Plain above the Blue Plateau. The latter has an elevation of 3,300 to 3,400 feet, whilst the Jenolan Plateau has an average elevation of 4,000 feet, varying from 3,800 to 4,400 feet; that is to say, the latter is, on the average, 700 feet higher than the former. A certain amount of local differential uplift of the Jenolan Block itself is probable, as it exhibits a wavy surface.

The greater elevation of the Jenolan Plateau is due to uplift which has not affected the Blue Plateau to the north and east. The outlier of Coal Measure rocks at Hampton, 700 feet above corresponding rocks at Lithgow, has already been noted. The only other explanation of this difference in elevation is an assumption that this rim of the coal basin saucer rises 700 feet in a few (7) miles, the direct distance between this outlier and similar rocks at South Bowenfels; which seems improbable, especially when considered in connection with the sandstone at Kanangra at 3,300 feet, just off the eastern margin of this Jenolan Plateau.

There also appears to be topographic evidence of both warping and faulting on the southern side of Kanimbla Valley. On the northern side of the Cox are the Kanimbla levels at 1,900 to 2,500 feet. On the southern side there is a uniform slope from this height right up to the Main Divide at 4,000 feet, thus giving the Cox a valley which is asymmetric about the river; this slope consists mainly of granite, with a few outliers of Upper Marine rocks. There does not appear to be any obvious reason why this rock rises to 4,000 feet on the divide when it occurs in Kanimbla at 1,900 to 2,500 feet, and is there subhorizontal, other than that given by the explanation that these uniformly-sloping ridges were once more level than now, and have been tilted by warping, thus giving the Cox its asymmetric valley. The Upper Marine rocks were apparently deposited on a granite peneplain, formed during the long period of erosion succeeding the Kanimbla Epoch of mountain building; and it does not seem that these con-

glomerates would be deposited along a steeply-sloping surface of fairly soft rock in such a position as that in which they are now found. In passing, it may be noted that the Kanimbla conglomerate, in common with the other Permian and Triassic strata, dips to the east, and an upward slope from north to south begins only to the south of the Cox, in the supposedly warped area.

This slope of the southern ridges is also noticeable in the case of the Black, Jenolan, and Mini Mini Ranges. Below Galong Creek, there is a marked discontinuity of slope in the Upper Marine beds as one goes from the north to the south of the Cox River. To the east of the River, the beds are practically horizontal, but on the western side they dip steeply northwards. The Cox flows a little to the south of this line of discontinuity, which may also be marked by slight faulting. There appears to be a slight vertical displacement here, but this cannot be definitely asserted.



Text-fig. 3.—Physiographic Fault at Kanangra Walls.
This fault is a revival of the old fault lines noted in Text-fig. 2, between the rising area to the west and the sinking area to the east. Kanangra Canyon is cut along this fault.

On the east the Jenolan Plateau is bounded by a definite scarp, which, although hardly recognizable as such in places, owing to confusion with the western margin of the Kowmung basin, is, nevertheless, fairly well defined (Text-fig. 9*C*). Perhaps the best place for observing this scarp is from the edge of "Big Plain" (4,000 feet), which is situated on the Kowmung-Wollondilly divide, about three miles to the west of Mt. Shivering. To the east of the plain, along

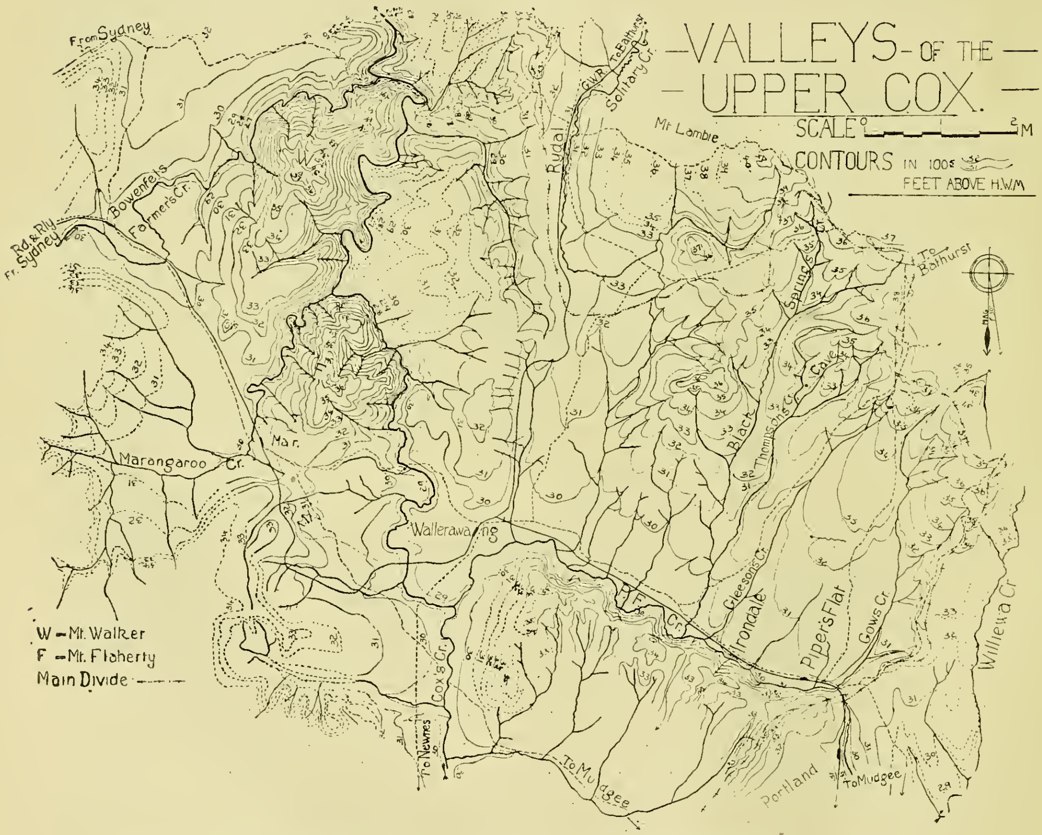
the dividing ridge, the land falls away steeply to 3,500 feet near the Mount, and thence, in a series of steps, to Bindook Swamp, at an elevation of 2,800 feet, which is some 300 feet below the surrounding country. Away to the north, a low scarp can be seen rising above the level of Kanangra Walls (Text-fig. 9*C*). This scarp rises to 4,300 feet, and forms the eastern edge of Jenolan Plateau. Between "Big Plain" and Kanangra Walls the scarp is much cut up, being trenched by great juvenile gorges.

On the west, the Jenolan block appears to be bounded by a definite scarp, part of which is the Stony Ridges to the east of Bathurst, as Andrews (1910) points out. From these considerations it appears that the Jenolan Plateau is composed of a broad, dome-shaped warp, which has been faulted along its north-eastern, eastern and southern edges.

I do not propose to describe the Blue Plateau in detail, as its salient features are already fairly well known. It consists of portion of an upwarped, slightly dissected peneplain, which is being trenched by stream action, resulting in the formation of deep, narrow canyons. A part of this has been described by Taylor (1923*a*). The plateau does not rise uniformly from east to west (Text-fig. 12), but, as Taylor points out, it exhibits "Steps" or "Treads", one at Mulgoa and one at Hazelbrook, both of which are very definite. Their respective elevations are 500 and 2,200 feet. The main change of slope occurs along a north-south line which runs through Katoomba, Mts Hay, Tomah and Wilson. To the east of this line, the average grade of the warp slope is of the order of 125 feet to the mile. To the west of this line, however, the slope rarely exceeds 20 feet to the mile. On the west of this line, therefore, the true plateau surface is found. Whilst these steps may be due to differential warping during a single period of uplift, their occurrence is not inconsistent with the theory, suggested by Taylor, that the present plateau surface has been formed by a series of non-contemporaneous warps and folds, and represents the algebraic sum of the same. This view has also been held by Mr. Andrews and the late Mr. Hedley.

The Kanangra Platform.—The two plateau levels are found in close proximity to one another at the head of Kanangra Creek, 20 miles to the south-east of Jenolan Caves, where the Kanangra "Platform" (Text-fig. 3) is located. Two main surfaces are found here, the upper being part of the Jenolan Plateau at an elevation of 4,000 to 4,250 feet, the lower level or Kanangra Platform having an elevation of 3,300 to 3,400 feet. The former consists of folded Silurian rocks, bevelled off across the bedding planes and granite, as on Boyd Creek. The mature upper valleys of Budthingeroo and Boyd Creeks are incised 300 to 500 feet in the plateau. The Kanangra Platform consists partly of horizontal sandstones, and partly of planed-off slates and quartzites. There is no change in slope or topography in the passage from one series to another. The upper valleys of Kanangra Creek are very little entrenched in this hard surface. Between these two levels there is a very definite scarp, 600 feet high, down which the road winds. It has hardly been cut into in this part by the small wet-weather streams. To the north, this scarp forms the western side of the great Kanangra Canyon. Kanangra Creek has taken advantage of the fault line, and has carved out a gorge which is 2,000 feet deep at the Walls, and somewhat over 3,000 feet deep between Gangerang Range and Mt. Guouogang. The streams plunge abruptly into this canyon from the platform in a series of high waterfalls, descending 1,500 feet in a mile.

To the south, the scarp consists largely of softer rocks, and has been deeply cut into by the powerful Kowmung streams, but it is still plainly discernible (Text-fig. *9C*). The 3,300 feet level is found along Gangerang Range on the eastern and northern sides. The peaks rise above this bench as monadnocks. Although approaching the Jenolan Plateau in elevation, Gangerang is a separate feature, and has only recently been made to appear comparatively low by the rise of the Jenolan block to the west of the fault. At Kanangra Walls therefore, the two plateau surfaces are found together, separated by a sharp fault. Comparatively recently, we conclude, the two surfaces were at the same level. The fault scarp continues south into the Wollondilly basin, but passes into a fold further to the north, in the Kanimbla Valley.

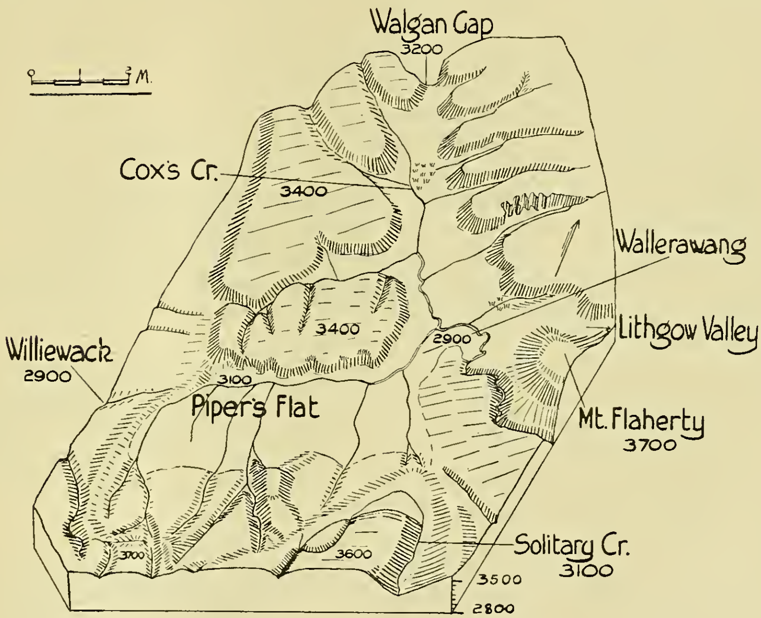


Text-fig. 4.—Contour Map of Wallerawang District.
Note the mature valleys broken only by the ancient monadnocks of Mounts Walker and Flaherty, the entrenched meanders of the Cox, and the asymmetry of the valley of Piper's Flat.

Wallerawang and Lithgow Valleys.—The upland valleys around Wallerawang and Lithgow form part of a valley system which extends across the Main Divide at Rydal and Piper's Flat, and includes the upper valleys of the Turon and Fish Rivers. In considering these valleys around Wallerawang, therefore, it is neces-

sary to remember that they are types of a valley-system which is not confined to the Cox basin. I propose to apply the name "Wallerawang Valley" to that valley about the 3,000 feet level which centres on Wallerawang, and extends from Wolgan Gap and Portland to Rydal and Wallerawang. "Lithgow Valley" will be defined as the valley stretching from Lithgow to Marangaroo, with a branch extending to the east of Mt. Walker towards Rydal.

The topography of these valleys and the associated plateau regions is clearly shown in the contour map (Text-fig. 4) and block diagrams (Text-figs. 5 and 7). The two valleys are actually continuous, but the monadnocks, Mounts Walker and Flaherty, which rise from 700 to 800 feet above the valley floor, divide it into two parts.



Text-fig. 5.—The Head of the Cox.
The broad valley of Piper's Flat Creek extends over the Main Divide into the Turon Basin. The southern margin has been affected by recent warping. The hard rocks of the plateau have been formed, by long continued erosion, into subdued ridges and mature valleys.

Wallerawang Valley, on the western side, varies in elevation from 2,900 feet at Wallerawang to 3140 feet and 3150 feet at Piper's Flat and Rydal respectively, and 3,175 feet in Wolgan Gap. The width of the valley along Piper's Flat varies from two to four miles, and the average depth is of the order of 400 feet. The valley of Cox's Creek is narrower, but of the same general depth. In general character the Wallerawang Valley is mature and, in common with the surrounding plateau, geologically varied. The valley floor is composed of Upper Coal Measure shale, Upper Marine shale, sandstone, and conglomerate, Devonian shale and quartzite, and granite. The plateau consists of Devonian quartzites and shales, Upper Coal Measure shales and sandstones (the latter to the north of Piper's

Flat), Hawkesbury sandstone, and granite. There has been little differential erosion between these rock types.

There is a gentle uniform rise along Cox's Creek, for example, from Wallerawang to Wolgan Gap, over Upper Marine, Upper Coal Measure and Hawkesbury rocks. The junction of different series cannot be detected by change of slope. A similar thing is true of ridges in this valley that run down towards Piper's Flat from the southern side. A traverse along the Main Divide to the south of Piper's Flat takes one over Upper Marine and Devonian rocks and granite. Again there is no notable change in topography with change in rock type. The hard sandstones now found on the plateau to north and west of this valley once extended right across the valley, as the outlier of sandstone on Round Hill (3,720 feet) on the southern side of the valley shows. This mature valley cannot, therefore, be ascribed to differential erosion in rocks of varying hardness, but must be the result of prolonged erosion when the land surface was not far above base-level, before the main uplift which formed the present plateau.

One of the most striking topographic features of the district is the asymmetry of the main valley, that of Piper's Flat Creek. The northern side of this valley, from Wallerawang to Portland, is a steep scarp against whose base the main stream flows. The southern side of the valley rises gently and uniformly, and is little cut into by the swampy streams that flow down it. The main stream receives no tributaries at all from the north, as the divide on that side is, in general, less than half a mile away. This feature has no apparent explanation, although there may have been a gentle uplift to the south, near Mt. Lambie, causing the stream channel to migrate northwards.

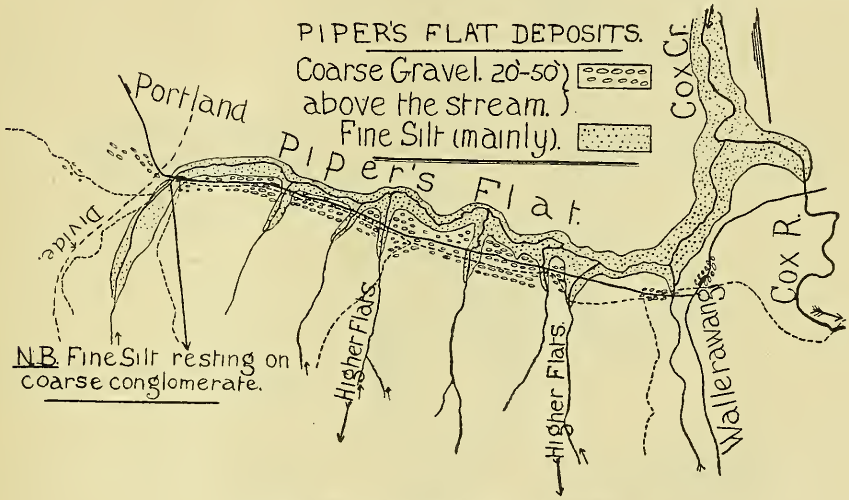
The valley of Cox's Creek is not so large or important as the other branch of Wallerawang Valley. Near Wallerawang, it is two miles wide; four miles above the town, however, it is but a half-mile wide, and narrows further towards Wolgan Gap. The same stream, which is the largest single stream in the head valleys of Cox River, is very little entrenched in its valley. Indeed, in parts, its tributaries have no definite channels through the swamps.

The streams of Wallerawang Valley differ somewhat in character. Cox's Creek and its tributaries run over swampy silt flats, and swing backwards and forwards over the valley. Piper's Flat Creek has a grade of about 30 feet to the mile, and is grading down its channel and cutting away the silt flats which it had previously deposited, which are up to a quarter of a mile wide. These silts are found along the tributaries up to four miles away from the main stream. On Thompson's Creek, for example, four miles from its mouth at Irondale, the silts are about 80 yards wide, and at least 10 feet deep, and are built up of peaty material at an elevation of 3,300 feet, 300 feet above the main valley. The streams are now just beginning to attack their head silts at 3,200 to 3,300 feet. These silts are found on most of the other tributary creeks of the valley, and on Solitary Creek, about two miles above Rydal.

One of the most interesting features of the valley is the occurrence of a line of gravels along Piper's Flat, up to 50 feet above the modern silt flats, and up to 30 feet thick. These gravels are found in a well-defined belt along the southern side of the valley (Text-fig. 6) extending over the Main Divide at least to the outskirts of Portland. Characteristic deposits may be seen near Wallerawang station and in the railway cuttings around Irondale. The pebbles vary in size from a couple of inches to a foot or more in length along the major axis, and are

ellipsoidal in shape. Grey and brown quartzites, the latter being spheroidal in shape, and containing beautiful specimens of *Spirifer* and *Rhynchonella*, various porphyries, some sandstone, and pebbles of decomposed rock containing mica, which might be weathered granite, are characteristic. They are much larger than the pebbles occurring in the lower silts and in the modern stream channel. The extension of the gravels over the Divide is interesting. The biggest boulder observed is found embedded in clay in a cutting right on the main Divide. It is porphyry, and is four feet high and two feet across.

The gravels are found on a variety of local rock types. Around Wallerawang, for instance, they are deposited on shale. In the vicinity of Irondale (e.g., at the mouth of Thompson's Creek) the local rocks are sandstone and grit. On the Main Divide, again, shale is found. It is apparent that the homogeneous gravels

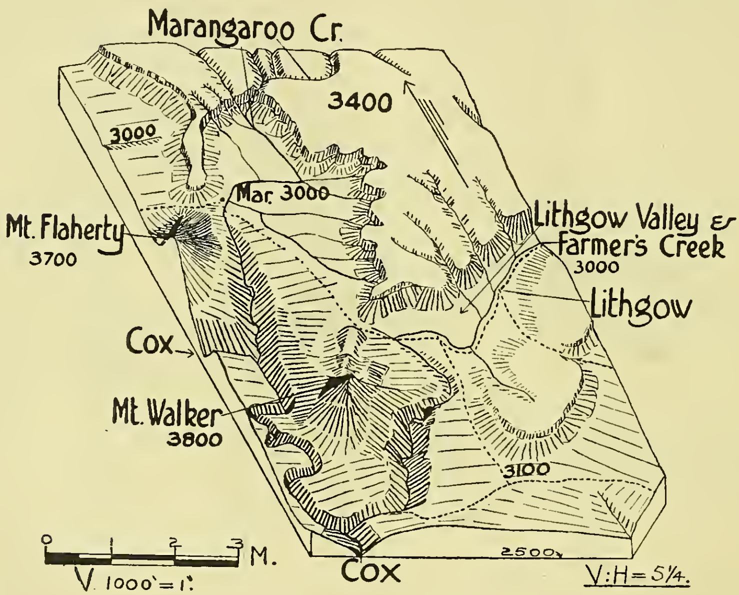


Text-fig. 6.—The Piper's Flat Deposits.
A line of gravel extends right along Piper's Flat over the Main Divide. Consideration of a number of factors shows the possibility of it being river gravel.

could not have been derived from the rocks on which they rest, although every rock-type found in them may have come from the district. The conclusion is, therefore, that they represent an old stream line about 50 feet above the modern flat, and have been put in their present position by stream action. Possibly, in time past, they extended over the area now occupied by the lower Piper's Flat.

An interesting confirmation of this view is obtained from Slaven's Cave, four miles up Thompson's Creek. This cave is situated on a hillside in hard porphyry, and was probably formed by the dissolving out of a small limestone pocket. Part of the roof has fallen in, but the cave is still about thirty yards across, and twenty to thirty feet high. A small hole leads into it from the top. The floor, which is about sixty feet above the modern stream, is covered with fine brown laminated silt, although now no water flows through the cave. Other unexplored caves occur below. The floor of the cave represents a higher old stream-level, which agrees with the evidence of the gravels.

In considering the character of the gravels, other points have to be borne in mind. Near Piper's Flat railway station, on Gow's Creek, coarse conglomerates are overlain by fine silts. Right along the southern side of the valley the soils are fine, with a few small quartzite pebbles. The Upper Marine conglomerates between Wallerawang and Rydal weather to a depth of about two feet, giving a fine sandy soil. On the other hand, the gravels along Piper's Flat are up to 30 feet thick, and are packed together in brown clay, especially in the type beds near Irondale. This clay is quite different from the surrounding soil, but might have been derived from weathering of granite pebbles. Be that as it may, the fact



Text-fig. 7.—Lithgow Valley, which was eroded near base-level. Note the course of Marangaroo Creek between the two monadnocks, the valley levels at 3,000 feet cut in a plateau of average elevation 3,400 feet, the entrenched meanders of the streams, and the valley divides of Marangaroo Creek.

remains that no weathered conglomerate in this district is similar to this well-defined line of gravel. There seems to be strong evidence, therefore, that these are recent stream deposits.

About two miles to the south-west of Wallerawang the Cox River plunges into a gorge, a good view of which is obtained from where the Portland Road crosses the stream. This gorge attains a maximum depth of 700 feet to the east of Rydal, and ends just above the Lett River, where it emerges from a well-defined scarp. Near Hartley the river is but little entrenched in the flat Kanimbla Valley. Below Wallerawang the stream is obsequent, a fact which is interesting when considering the past stream history. This fact bears no relationship to the silt flats along Cox's and Piper's Flat Creeks, which could not have been laid down along the present slope. Also, there is no silt in the broad valley

to the east of Wallerawang, just above where the stream flows into the higher land. An account of Solitary Creek is given when the Cox Divides are discussed.

Lithgow Valley (Text-fig. 7) is found on the same level as Wallerawang Valley, and consists of Upper Coal Measure and Upper Marine rocks, and granite. To the north rises the Blue Plateau, whilst to the south the old mountain masses of Mounts Walker and Flaherty are found. The valley is about 500 feet deep, from one to three miles wide, and is drained by Farmer's and Marangaroo Creeks. The former shows entrenched meanders along the lower part of its course, where it has cut a steep gorge, 500 feet deep, in the valley levels near the Cox junction. The divide between this stream and Marangaroo Creek to the west of Bowenfels is almost non-existent. The break in the divide is so large that the valley between Bowenfels and Marangaroo is continuous. In view of this fact it is all the more remarkable to find Marangaroo Creek flowing into the high mountain block (Text-fig. 4). The stream is certainly antecedent, and this part of Lithgow Valley is the result of differential erosion. The stream originally flowed over a plain of Hawkesbury sandstone between the two residuals. After the uplift which resulted in the formation of the Lithgow and Wallerawang levels, the stream graded a large part of its course, but could do very little lateral cutting near its mouth on account of the extreme hardness of the steeply-inclined quartzites. Further upstream, however, after cutting through the hard Hawkesbury beds, it discovered the softer Upper Coal Measure series below, and excavated a wide valley in them. A large relic of the original plateau is preserved on the 3,300 feet level to the south-east of the junction with the Cox. The upper and middle courses of Marangaroo Creek were determined by the master-joints of the Hawkesbury sandstones (i.e., in north-south, and east-west lines). The lower course was determined by the strike—about 20 degrees east of north—of the Devonian quartzites. The lower course of the creek shows deeply entrenched meanders, relics of the old plateau surface stream.

The upper course of Farmer's Creek has also been determined by joints. The lower course is old, and is mainly in softer granite and slate, avoiding the hard quartzites. Owing to the comparatively soft granite along its lower course, the stream has, unlike Marangaroo Creek, been able to prolong the upper (Lithgow) valley levels right to the Cox, although now it is deeply entrenched in them, below Bowenfels. A small plateau at 3,400 feet is found to the east of Farmer's Creek. The eastern side is a steep cliff—known as Hassan's Walls—which overlooks the Kanimbla Valley. The 3,100 feet level extends within a mile of Hartley, which is at 2,400 feet.

With regard to the idea of benching as the main cause of the valley, as suggested by Mr. Sussmilch, I have no doubt that benching is mainly responsible for the level valley above Lithgow, but has been only a minor factor in the evolution of the remainder of the valley floor.

Boyd and Budthingeroo Creeks.—The topography of the country around the heads of Kanangra River, Boyd and Budthingeroo Creeks is varied. Three series of valleys are found at various levels. Of these, the valleys of Kanangra Platform (3,300 feet) have already been described. The upper valleys of Boyd and Budthingeroo Creeks are at 3,750 and 3,950 feet respectively. They are mature in type, being more than one mile wide, and are occupied by sluggish streams flowing over swampy flats. On the traverse line they are both found at a depth of 300 feet below the plateau, which varies from 3,950 feet to the east of Boyd

Creek to 4,250 feet between the two streams, attaining a like elevation to the west of Budthingeroo Creek. Here the principal rocks are granite and slate, giving a heavy clay soil. These valleys are referable to the Lithgow and Wallerawang Valley class, and are similar to those at Oberon and Shooter's Hill.

In this vicinity, along the Tuglow-Kanangra divide, mature relic valleys at an elevation of 4,100-4,200 feet are found. These are 200 to 300 feet above the previous series, and drop steeply into the latter. These valleys are cut about a hundred feet in the soft Silurian rocks of the Jenolan Plateau, resembling the mature valleys half-way between Hampton and Jenolan, and the early mature valleys at Wentworth Falls and on the Kanangra Platform. Their present extent in this district is not great, but they appear to be relics of the Tertiary surface.

Retreat, Tuglow and Fish Rivers.—The upper valleys of these streams also belong to this series (i.e., Lithgow), although they are found at variable altitudes. The Retreat River at Porter's Retreat is 600 feet below the plateau, at 3,500 feet. The Tuglow flows in a mature valley, 300 feet below the plateau surface, which is at 4,100 feet; whilst the Fish River at Oberon flows at 3,500 feet, or 500 feet below the plateau.

These three valleys are cut in highly-inclined Silurian strata and in Devonian granites, and are, consequently, not due to any such action as benching, which was partly responsible for the formation of Lithgow Valley. They were formed under much the same conditions, as regards elevation, as the Wallerawang and Lithgow Valleys, are up to two miles wide, each having similar dimensions. One is struck by the fact that the Fish River at Oberon, which flows over marshy flats, is notably more mature than the same stream at Tarana—and, for that matter, Solitary Creek above that point—the latter valleys appearing to be of a "masked juvenile" type; that is to say, in point of age the valleys are young, but, owing to the softness of the decomposed granite in which they are cut, a stage closer to maturity has been reached than would have been the case in the somewhat harder rocks at Oberon, for example. The grades of Solitary Creek between Rydal and Tarana, and the Fish River above Tarana, towards Oberon, are not typical of mature streams, being of the average respective orders of fifty and forty-five feet to the mile. Below Tarana, the Fish River has an average grade of eleven feet per mile into Bathurst. The thalweg of the river is that of a rejuvenated stream, supporting the conclusion that the wide valley at Tarana is of recent formation, being much younger than the more mature valley at Oberon in harder rocks.

Throughout their lengths, the two branches of the Fish River show well-developed meanders, which date back either to the pre-uplift or the Lithgow Valley stage, the former being the more probable. The powerful Tuglow has cut back into the soft Silurian rocks, the head of erosion now being within three miles of the Main Divide. This short length of upland valley is, however, very mature. The Retreat River Valley shows a valley-in-valley form, the main valley at 3,500 feet being trenched to a depth of a hundred feet at Porter's Retreat. Below here, it appears to run into deeper gorges. The occurrence of a zone containing these mature valleys entrenched from three to six hundred feet in the plateau surface is very interesting. Similar valleys are found on the Middle Wollondilly and the Cookbundoon Rivers, as I hope to show in a subsequent paper, but do not occur over the main mass of the Blue Plateau, although they are found along the Wallerawang to Mudgee railway. These facts are of significance when considering the folding and warping movements which the area has undergone.

Text-fig. 8.—Megalong Valley.
Note the broad, flat floor of the valley, the great meanders of the Cox, now entrenched in the main valley floor, and the remarkably uniform increase in the depth of entrenchment of the streams from north to south. The undissected valley floor extends ten miles further northward to Hartley.

Kanimbla and Megalong Valleys.—Looking south from Mt. Walker, near Lithgow, a splendid view is obtained across the floor of the great Kanimbla Valley to Mt. Mouin, twenty-five miles away. Here, three cycles of erosion are clearly presented, which have resulted in the formation of the plateau (first level), the level Kanimbla Valley (second level), and the Cox gorges respectively. There is very clear evidence that Kanimbla Valley was formed not far above base-level.

The northern part of the valley is clearly separated from the Wallerawang levels, the respective average elevations being 2,200 and 3,100 feet. This is especially the case near Hartley, where the two—Kanimbla being here at 2,400 feet—are a little over a mile apart.

Kanimbla Valley—the southern part of which is called Megalong—extends from Hartley in the north to Mt. Mouin in the south, and from the northern cliff ramparts near Blackheath to Lowther. It has a length of twenty-five miles, a width of ten miles, and a depth of 1,100 to 1,500 feet. To the east of the Cox the valley is gently undulating; but on the western side, the valley ridges rise uniformly to the Main Divide in the vicinity of Hampton at 3,800 feet. As I have already pointed out (under the heading "Blue and Jenolan Plateau") there is very good evidence that the western side of the valley has been subjected to warping. It might be added that the uniform rise of these southern valley ridges —some of which are granite, and others Devonian rocks, both showing long outliers of Upper Marine rocks in parts—from the Kanimbla levels to the Divide is, of itself, good evidence of such warping.

The valley is thus distinctly asymmetric, but the flat northern side varies in elevation from 1,900 feet on Megalong and Blackheath Creeks to 2,600 feet between Galong and Breakfast Creeks, the average being about 2,200 feet.

The characteristic features of the valley are shown by a study of the eastern end, Megalong (see Contour Map, Text-fig. 8 and Plate xix, fig. 2). The northern and eastern confines of this valley are formed by great ramparts of Triassic sandstone, from which the softer talus rocks slope away at 18 to 20 degrees into a level valley. This valley is occupied by four main streams, Breakfast, Galong, Megalong and Pulpit Hill Creeks. The lower courses of the two former streams have cut great gorges in the valley floor, whose deepest parts are only 700 feet above the sea. They alone of the northern Kanimbla streams make accordant junctions with the Cox. Megalong and Pulpit Hill Creeks have their whole courses along the level valley, and make highly discordant junctions with the Cox. The former stream plunges down five hundred feet within a few hundred yards into the river.

The canyon which the river has cut in the relatively level valley deepens rapidly downstream. At the junction of Megalong Creek, this gorge is 800 feet deep; whereas, a little below Galong Creek, it has attained a depth of 1900 feet, the great change being due to a rapidly falling stream and a rising upper valley. A feature of the valley is the fringe of benches of Upper Marine sandstone and conglomerate on the northern and eastern sides. Much of this bench is bounded, on the outer side, by cliffs and small precipices up to eighty feet high. The main interest of the Megalong Valley lies in the series of valleys found between 1,900 and 2,300 feet (see Contour Map).

The early mature valleys at the head of Breakfast Creek and in Megalong Gap are of this series, at 2,200 feet; and occur in sandstone and conglomerate. The upper valleys of Galong Creek at 1,900 feet occur in granite, 400 feet below

the conglomerate. Between the two streams, the eastward dip of the conglomerate is of the order of a hundred feet to the mile over a range of two miles; whilst, from north to south it is laid down on an undulating granite surface. Megalong and Pulpit Hill Creeks flow partly over Upper Marine rocks and partly over granite. There is little change in topography in the passage from one series to the other, and no noticeable change in stream grade. From this it is to be inferred, that differential erosion has not played a great part in the formation of the valley floor.

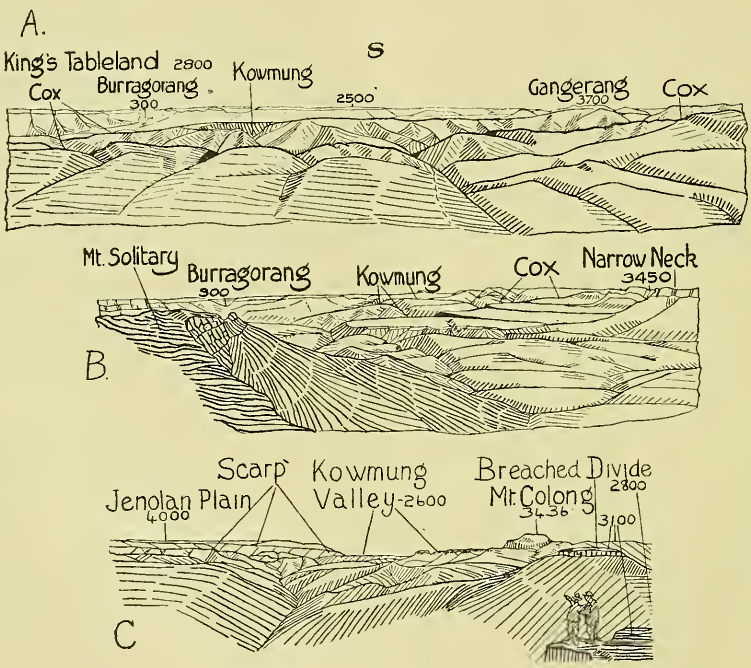
There are fairly extensive silt flats along Megalong and Pulpit Hill Creeks, consisting of flat, badly-drained silts, up to four hundred yards wide, and of some depth. These are mainly of sand; Plate xix, fig. 2, gives a typical view. These flats extend right up to the steep talus slopes, and appear to be swamp or lake deposits. They contain no stones. Obviously, these flats could not have been formed under existing conditions, as the streams are just trenching them and washing away the earth. They must have been deposited along the level valley floor before the lowest courses of the streams had their present grade, that is, before the Cox cut its deep modern gorge in the valley floor, at a time when this valley floor was near base-level.

It appears highly probable that the warping of western Kanimbla affected the valley to the east of the Cox, as the edges of these eastern ridges adjacent to the river are somewhat higher than the land a little further to the east in the valley. This is also the case with Blackheath Creek. Such warping, whether near, or a good deal above base-level before the cutting of the modern gorges, would cause the creeks to slow down, depositing part of their loads of rock waste to form these flats which are, of course, rather temporary features.

The topography of the remainder of Eastern Kanimbla is very similar to that of Megalong Valley, being, possibly, a little more subdued on account of the greater predominance of granite. The silt flats of Blackheath Creek at 2,000 feet are very extensive, whilst the valley of Lett River is very flat.

When we turn to consider the modern course of the Cox, we are struck at once by the variations in the amount of dissection going from north to south. Near Hartley, the river is entrenched only a couple of hundred feet in the level plain. At Megalong Creek the depth of entrenchment is 800 feet; whilst for twenty miles below Galong Creek the canyon of the Cox is nowhere less than 1,900 feet deep. Turning to the tributaries, the variations are still more striking. Lett River, Blackheath, Pulpit Hill and Megalong Creeks make discordant—in the latter cases highly discordant—junctions with the river. Turning to the western side, Kanangra and Jenolan Rivers make strictly accordant junctions with the Cox. Little River and Gibraltar Creek are not strictly accordant, whilst the junctions of the other streams, Cullenbenbong, Long Swamp and Lowther Creeks, for example, are discordant. The character of the gorge is clearly shown by Text-fig. 1. The effective head of erosion for the tributaries is now at the junction of Megalong Creek, although the Cox itself has cut back further. From these considerations, two definite conclusions can be drawn: firstly, Kanimbla Valley is mature, and a fairly ancient feature; secondly, the modern gorges of the Cox and its southern tributaries have been formed recently. In other words, this valley floor has only recently been raised far above base-level. Summing up, the Kanimbla Valley represents a stage, rhythm, or pause in the uplift of the plateau, of fairly long duration.

The Relationship between the Kanimbla and Wallerawang Levels.—The change from the Kanimbla to the Wallerawang levels—from Hartley to South Bowenfels —is marked by a great change in stream-valley topography. At Hartley, the Cox is little entrenched. Going up the river, however, a deep gorge is entered, which extends almost to Wallerawang, attaining a maximum depth of 600 feet near Farmer's Creek. The lower parts of Farmer's and Marangaroo Creeks have also cut deep canyons in, or, in the latter case, below the 3,100 feet level. These gorges extend some three miles up the streams, and are only just beginning to attack the soft upper valley levels. Of the twenty-four miles of river line between



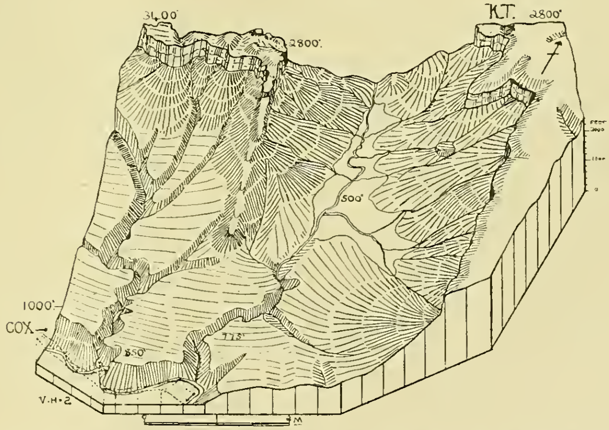
Text-fig. 9.—The warped valley of the Kowmung River. (*a*) shows the rising warp as viewed from Mt. Mouin. (*b*) gives a view looking to the south from Mt. Solitary. In each case the warped valley floor is seen to be little dissected. (*c*) shows the old valley floor looking northwards from Bindook Swamp. Note the striking "valley-in-valley" structure, and the fault scarp to the west (left).

Hartley and the head of the Cox, only the lower thirteen miles are characterized by gorges. The junctions of these two streams with the Cox are accordant, in strong contrast to the discordant junctions of the tributary streams in the softer rocks below Hartley. The limited extent of the gorges, the steep grade of the river—forty feet per mile—and the fact that Solitary Creek runs 500 feet above the Cox, and is separated from it by an insignificant valley divide, are certain evidence that the gorges have been recently cut, with a lower limit of 2,200 feet (Hartley). That is, the Kanimbla levels have acted as a temporary base-level

of erosion for the Wallerawang levels. The physiographic fault between the two is evidence of the same thing (see Text-fig. 12).

The dissection of the higher levels has only been made possible recently by their uplift above the Kanimbla levels. That is, both the Wallerawang and Kanimbla Valley systems were formed at a constant level, and were co-extensive. Thus the upper valley once extended without a break from Piper's Flat and Wolgan Gap to Mt. Mouin. The consequences of this conclusion are fully discussed when the folding movements are considered.

Jamieson's Valley and the Kowmung Basin.—The lowlands of Jamieson's Valley are separated from the Kanimbla levels by a uniformly sloping surface, which has not been much dissected apart from the canyons of the Cox and Kowmung Rivers. The steady slope from Jamieson's Creek to Gangerang Range on the south, and Mt. Mouin on the north of the Cox, is a very striking feature. The Cox and Kowmung Rivers have cut extremely deep and narrow gorges in this surface, which vary in depth from zero at Black Hollow Creek to 2,000 feet between Mt. Mouin and Gangerang. The smaller streams flowing from the foot of Mt. Mouin are but little entrenched in this surface, although, as we have seen, the more powerful streams a little further up the Cox Valley, such as Breakfast and Kanangra Creeks, are flowing in very deep gorges similar to that of the Kowmung.



Text-fig. 10.—Lower Jamieson's Valley, showing the antecedent course of Jamieson's Creek and the stream flats due to the rise of the warp to the south-west. The warp surface is very little dissected, and rises steadily towards the south and south-west. Cedar Creek (near the western margin) is a subsequent stream. (Drawn from Contour Map.)

Jamieson's Valley is bounded on three sides by precipitous cliffs of Triassic sandstone, the open southern margin shading almost imperceptibly into the Kowmung Basin. But for the fact that the Cox River cuts across here, it would be impossible to distinguish between the two features. On the north-east, the plateau rises 2,300 feet above the valley floor, but on the south-western margin, the elevation above the tilted western margin is only about 1,000 feet (Text-fig. 9).

There are extensive silt flats along the middle portion of Jamieson's Creek in the vicinity of 500 feet (see Text-fig. 10) similar in many respects to those of

Megalong. Along Reedy Creek especially, islands rise from these flats like islands from the sea. The flats themselves are absolutely level, and consist of fine sands and clays. There are no large stones in these silts, and very few small ones. Doubtless there were some in the original deposit, but owing to the subsequent action of air and water over a fairly lengthy period, they have been disintegrated.

I am strongly of the opinion that these flats are due to the deposition of silt in a body of water. They are not due to the occupation of the valley by swamps, as peat is not found in them. Sword grass and rushes are absent, and gum trees and grass grow right to the creek. For all that, the heads of the flats are, as yet, badly drained, and are submerged in wet weather to a depth of several inches.

The origin of these flats is fairly obvious. The streams had cut down almost to base-level along their lower courses, forming a flat-bottomed valley. The edge of a warp has risen across the lower three miles of Jamieson's Creek, which was not able to keep pace in downcutting with the rise of the warp. The stream was, therefore, partially dammed, causing the formation of a lake on the upstream side, in which silt was deposited. This lake acted as a temporary base level of erosion for the Jamieson's Creek basin, and, in course of time, became almost silted up.

At the mouth of the creek, the warped surface has reached a height of 775 feet above sea-level, 275 feet above the silt flats at 500 feet. Thus the creek is antecedent. On the southern side of the Cox, at the head of the Kowmung River, the warped valley surface has attained an elevation of 2,800 feet. The lower part of Jamieson's Creek, which has a meandering course, is entrenched some 300 feet in the surface, and flows in a steep gorge cut in hard conglomerate. Headward erosion is just beginning to affect the lower margin of the flats, which have been trenched to a depth of twenty feet. The upper portion is, as yet, practically unaffected, although some terracing of the order of five feet, is shown at the junction of Reedy and Jamieson's Creeks.

The conditions of deposition appear to have been very similar to those which prevailed on the Nepean River during the deposition of the silt lakes at Wallacia and elsewhere, the general characteristics of the two deposits showing a marked similarity as regards material and stratification.

The other stream of Jamieson's Valley does not show these features, being a revived ancient stream at present having a consequent character, and is uniformly entrenched in the warped plain. In general, Jamieson's and Megalong-Kanimbla Valleys are closely related from a physiographic point of view.

The Kowmung Basin.—The topography of the Kowmung Basin is comparatively simple. In brief, the area consists of a ramp (Figs. 1, 9), which rises from 300 feet in the north-eastern corner to 2,800 feet in the south, at Bindook Swamp, and 3,000 feet near Kanangra Walls to the west. It is bounded on the east by the Tonalli Range, which varies in height above the ramp from 1,600 feet in the north to 300 feet in the extreme south, on the Wollondilly divide, the actual respective elevations of the range being 1,900 and 3,100 feet above the sea. The western edge consists of a scarp—partly valley wall, partly fault scarp—whose height above the ramp varies from 1,600 feet at Gangerang to 800 feet in the vicinity of Mt. Shivering. This surface has a remarkably uniform upward slope from the north to the south, Kiaramba Ridge, to the east of the Kowmung, being typical (Text-fig. 12*C*).

Its surface consists of Silurian, Devonian and Upper Marine rocks, and must, therefore, be a surface or plane of erosion. The streams have trenched this surface with profound juvenile gorges, up to 2,000 feet deep, but the upland form is but little altered, mature valleys being preserved right on Kiaramba Ridge. The main features of warping and past stream history are discussed under separate headings.

Jamieson's Valley and the Kowmung Basin form a great oval-shaped valley which opens in a general way into the Wollondilly Basin to the south. The outlet of the Cox is hardly noticeable in the eastern wall of this valley, being only a mile and a half wide at the top. Byrne's Gap, at the head of the Tonalli River, which is not occupied by any stream, is almost as wide. The true beginning of the "bottle-neck" constriction of the Lower Cox-Warragamba is not below the Wollondilly junction, but below the King's Tableland-Tonalli Range scarp.

At present, the 300 feet level is the base-level of erosion for the Kanimbla Valley. This latter surface continues to the east of Megalong Gap and Mt. Mouin, sloping thence uniformly, as an almost unbroken surface into Jamieson's Valley.

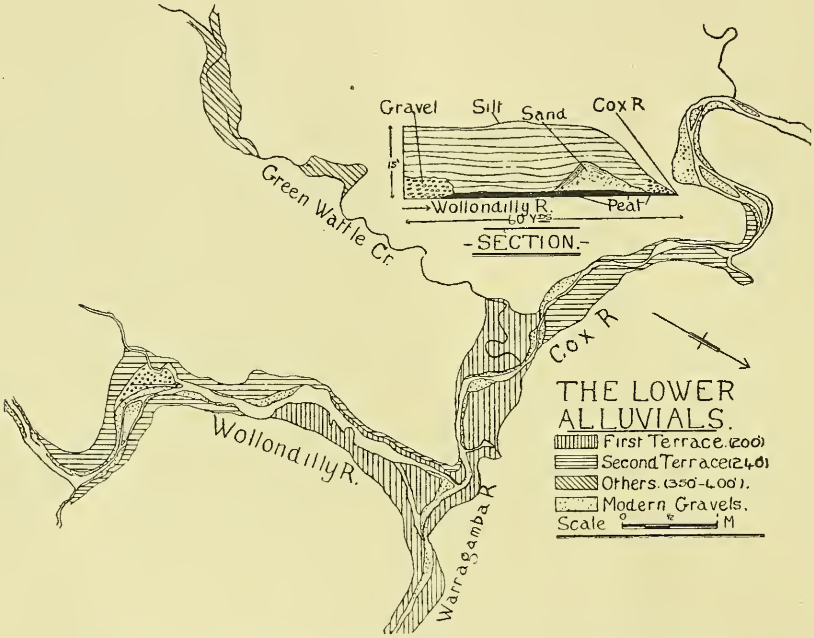
Valleys of the Lower Cox-Wollondilly.—The valleys of the Lower Cox and Wollondilly are excavated in the steps and slopes leading up to the main plateau. Here the streams have a low grade and run in deep valleys, whose depth varies from 2,000 feet in Upper Burragorang, and 1,700 feet in Lower Burragorang and the Lower Cox Valley, to 1,400 feet at the junction of the Cox and Wollondilly. The lower thirty miles of the valley of the Wollondilly are known as "Burragorang". An idea of the general appearance of these valleys is gained from Text-fig. 1 and Plate xx, fig. 2.

The Lower Cox-Wollondilly system comprises five valleys—namely Burragorang, the lower valleys of the Cox and Nattai Rivers, and those of Green Wattle and Lacy's Creeks. The average width of the Burragorang between cliff lines is somewhat less than two miles (contrast with the eight-mile-wide main Kowmung Valley). That of the Lower Cox is up to a mile and a half wide; whilst the other three vary from half to three-quarters of a mile in width. The floors of the two main valleys are flat, and consist of rich alluvial deposits up to half a mile wide, which the rivers are trenching. A typical section at the junction of the two rivers is shown in Text-fig. 11, and shows small water-worn pebbles and peat underlying horizontally-bedded silts consisting of alternate layers of roots and plant remains, and plain silt, with thin layers of peaty material. The alluvials extend up the Cox above Pearce's Creek, and up the Wollondilly above Byrne's Creek. Terracing is very noticeable at the junction of the two rivers, three terraces being found at 180, 200 and 240 feet, the second being the most important. The last-named is met with on Pearce's Creek on the Cox, and also above Fitzpatrick's Crossing on the Wollondilly, three miles above the Cox junction. Further up the Wollondilly, higher terraces are met with. At the mouth of Byrne's Creek, twenty miles above the Cox, a level detritus and silt plain occurs at 420 feet. A certain amount of uplift towards the south is very probable. The silts extend about a mile down the Warragamba, the lowest reliable level being at 150 feet above the sea, below Gogongolly Creek. The thickness of the deposits in any one place cannot be exactly determined, but the maximum is probably of the order of fifty feet at the Cox-Wollondilly junction (this is the 200 feet terrace).

These silts appear to be very similar to the silt lakes found on the Nepean at Wallacia, Penrith and Camden, and appear to have had a similar origin. In this case, a rising warp across the Warragamba caused the formation of a lake, as the

stream was not able to cut down as rapidly as the barrier was elevated. Pauses in the uplift are indicated by the formation of the root beds, when the river was able to cut down and partly drain the lake. A period of standstill is now allowing the streams to cut down and erode the deposits.

These valleys are enclosed by rampart-like cliffs of Hawkesbury sandstone, which form almost unbroken walls. Two particularly fine lengths occur, the "Burragorang Walls" and the Walls of Green Wattle Creek. The former are on the eastern side of the Wollondilly above the Nattai junction, whilst the latter



Text-fig. 11.—Silts and Terraces of the Lower Cox-Wollondilly. The section proves the nature of these silts, showing that they are old lake deposits. The peat and root beds are particularly notable. Rising terraces further to the south indicate uplift in that part.

are about five miles above the Cox junction with that stream, and also have a westward aspect. In both cases, the cliffs are quite straight, and almost unbroken, and are not even notched by tributaries. Thus they are quite different from the cliffs of the Grose and Jamieson Valleys, which are deeply cut into, even where mere wet-weather streams cross them. This absence of tributaries seems to indicate a recent formation for these streams, a conclusion supported by absence of meanders, whilst the straight and unbroken character of the cliff lines would appear to indicate a recent date for the excavation of the valleys themselves, a conclusion, as we shall see, in line with other evidence.

The course of Green Wattle Creek is interesting. Seven miles from the Cox the valley is almost a mile wide, the eastern edge being the straight walls just mentioned (Plate xx, fig. 1). The floor at 400 feet consists of sandy silts with layers of water-worn pebbles and of peaty material. The creek is slow and wide, running in a sandy channel. A mile below this point, the stream runs into a rocky

gorge, cut in a terrace of hard Permian sandstone, which is fairly extensive at 600 feet. On the stream level between three and four hundred feet, there are flat terraces up to a quarter of a mile broad, and to half a mile long, mainly on the western side at the mouth of tributary gullies. These alternate with stretches of rocky gorge cut in grey tuffs. The last mile is across the Cox Valley flats to the river, with which the creek makes an accordant junction, after wandering over the flats. The river has apparently dragged the mouth of the creek downstream.

A feature of the plateau surface in this part is the occurrence of lines of sandstone residuals, or rock hills, about two hundred feet high. One line is found along the King's Tableland; others between Black Hollow, Green Wattle, Lacy's Creeks and the Wollondilly River; and another very fine line between the Wollondilly and the Nattai (Plate xx, fig. 2). In some cases, these residuals occur right on top of the modern cliffs, and appear to have extended at one time into the area now occupied by the valleys. They are hemi-spheroidal to conical in shape, cut out of sandstone of uniform hardness, and are most likely old basalt caps or residuals from which the basalt has been removed. These lines are parallel to the Mt. Tomah-Mt. Wilson residuals. No other explanation is apparent. The residuals indicate that the older valleys (pre-uplift) in this part were a good deal narrower than the modern ones. The fact that all these valleys are of the same order of magnitude is important when considering the evolution of the stream system.

The Warragamba Gorge.—This is, perhaps, the most remarkable of all the Cox-Wollondilly canyons, not as regards depth, for its maximum depth, 1,600 feet, is only half that of Kanangra Creek Canyon, but on account of its extreme straightness. Of a course of fourteen miles between the Wollondilly-Cox junction and the Nepean, nine miles are almost perfectly straight, even the ends of the gorge being only slightly bent. Thus this stream is eminently young, and contrasts strongly with the upper and middle sections of the Cox which flow in great meanders.

For the greater part of its length the sides of the gorge are almost precipitous, the river occupying the whole width of the bottom of the gorge. Above "The Bend", three miles below the Wollondilly, the gorge widens notably, as the soft Upper Coal Measure shales, rising gradually towards the west, are exposed to the attack of the stream, which has cut terraces or benches at high flood level. The entrance from Burragorang (Taylor's "Warragamba slot") is considerably wider than a view from that valley would appear to indicate. It is actually a narrowing continuation of the Lower Cox or the Lower Burragorang Valley.

Going downstream into a narrowing canyon, sandbanks and terraces are met with until five miles below the Wollondilly. As the cliffs close in on the river, great boulders are found in the river bed, and on the hillsides up to high flood level, sixty to seventy feet above the stream. Coming to Monkey Creek the gorge, now sixteen hundred feet deep, has narrowed into a ravine. Immense boulders up to twenty feet long, fifteen feet high and ten feet wide are found by the side of the river, whose channel is, however, fairly clear. The cliffs come down steeply almost to the water's edge. Towards the lower end, within two miles of the Nepean, another change is noticed. The banks of the river are almost perpendicular, and the zone of scrub, till now so conspicuous a feature within the flood limits, is absent. This is the steepest-sided part of the canyon, although it is only three to six hundred feet deep. At the junction with the Nepean, near Wallacia, shingle beds are met with. Within the Warragamba gorge, the shingle beds extend only three miles

below the Wollondilly—an indication of the swiftness of the flood waters in this narrow track, although the average grade of the river is only seven feet per mile. The zone of scrub on either bank of the river is a most remarkable feature. There are no trees within the flood limit, but scrub, with little undergrowth, is found, with the characteristic downstream bend. Above this zone rise the forest trees, grey gum and turpentine. The scrub zone is littered with boulders and flood debris, and is almost impassable. The bottom of the gorge thus has the appearance of a lane—the river—running between footpaths which are, in turn, bordered by hedges, forest trees and cliffs.

The sides of the main gorge are indented by tributary gullies, all of which are discordant, coming in a little below high flood level. As these creeks only run in wet weather, they could hardly be expected to cut down to the normal low river level. Uplift had also something to do with the arrangement, as tiny wet-weather streams could not keep pace in downcutting with the main stream. The position of the uplift which caused the formation of the Cox-Wollondilly silt lakes is of some importance. An uplift of the order of three to five hundred feet at Wallacia partly blocked the Nepean in a similar manner. As this uplift is across the Warragamba also, and took place very recently, as is indicated later in this paper, it could readily have caused the partial blocking of the Warragamba also, and the formation of silt lakes at the head of the canyon. Recent faulting has also taken place across Monkey Creek, according to Willan.

The significance of the newly-formed Warragamba with regard to the question of past stream flow will be discussed later.

Main Folds and Warps of the Area.

The folding and warping movements which have affected the regions adjacent to the Sydney Basin have been noted by Andrews (1903) and described fully by Taylor (1923). Other contributions to the subject include Professor David's papers on the Monocline (1896) and the Kurrajong Fault (1902), and papers by Taylor, more specifically his contribution to the Pan-Pacific Guide Book (1923); Willan's "Geological Map of the Sydney Basin" (1925) is also very valuable for the area which it covers. It will be seen that the main Blue Plateau has scarcely been touched.

Surrounding the Sydney Basin, which is a neutral or "stillstand" area, there are three main lines of warping—the northern or Hawkesbury Warp, including the country between North Sydney and Broken Bay; the Blue (Mt.) Monocline fold and warp system, which extends from the north of Kurrajong, southwards to Mittagong; and the Southern Warp, or Nepean Ramp, which, beginning at Cook's River (Sydney), merges into the southern highlands in the vicinity of Moss Vale. This much is proved, but the actual uplift of the main mass of the Blue Plateau has, as yet, been a subject of conjecture. In this account, I propose to treat the Cox Basin specifically, making some reference to relevant adjacent areas.

General Considerations of the Folding.—In making a general survey of the country between the Hunter River basin and Lake George, one is struck by the regular variations of altitude. This is particularly the case near the coast, where the Sydney Basin lies between two high areas of warped country. Further to the west, in the region with which this paper deals, variations of altitude are noticeable, which can be correlated, in part, with the littoral features.

The dominant movement of uplift in the eastern portion of New South Wales has been extended along north-south lines. If it is thought that uplift took place simultaneously along the whole line, variations of altitude from place to place would be due to simple differential uplift; if the view is taken that these highlands have been built up by a system of rather localized uplifts, warp and fold lines with an east-west trend would be found, marking the northern and southern limits of each movement of uplift. Such lines of warping are found to the north and south of the Sydney Basin, and continue, as will be shown in the latter case, to the west.

The eastern Highlands of this State fall into three groups—the New England Plateau, rising to 5,500 feet; the Central, or Blue. Plateau, with a maximum elevation of 4,400 feet; and the Southern Highlands, extending from the Federal Capital Territory to Kosciusko, which have peaks over a wide area from 5,500 to 7,200 feet above the sea. The northern and central sections are separated by the Cassilis Geocol, at 2,000 feet; and the central and southern massifs by the Lake George geocol, at 2,100 to 2,300 feet. The Central is the most limited of the plateau massifs. A good deal of its elevation appears to be due to the overlapping of the main northern and southern uplifts in that section.

In dealing with the uplift of this central area included in the Cox region, the more recent earth movements have been described and located first, and the earlier folding movements identified by a process of elimination.

The Mulgoa Step.—The section of the eastern face of the monoclinal fold extending from Kurrajong Heights to Douglas Park is the result of very recent uplift. This is clearly shown by the silts of the Lower Cox-Wollondilly. Obviously the silts are of more recent age than the valleys in which they are found, these valleys, in turn, being younger than the uplift which led to their formation. The uplift responsible for the partial blocking of the Warragamba was younger than the Lower Cox-Wollondilly Valleys, and, consequently, much younger than the uplift which led to the formation of those valleys. This same uplift led to the blocking of the Nepean above Wallacia.

It is suggested that this last phase of uplift only affected the country for a limited distance behind the modern monoclinal face, over a maximum width of six miles, but generally less than that, and was responsible for these features:—

(i). Most of the uplift and faulting at Kurrajong Heights, which extends to the south across the Grose River, and across Blue Gum Creek, to the north of Springwood.

(ii). The anticline at Glenbrook, with a fault on its western side to the south-east of Glenbrook station.

(iii). Uplift at the junction of the Warragamba and Nepean Rivers, together with folding and faulting at Bent's Basin, faulting across Monkey Creek and at Razorback Range. Most of these features are clearly shown on Willan's map.

Additional proof of the recency of this uplift is given by the undissected nature of this eastern edge; even the soft shales of Kurrajong, lying on a steep slope, are practically undissected. At Mulgoa, the uplifted step to the east of the Nepean, which has undergone a general uplift of 500 feet, rising to 800 at one point, has been but little attacked by streams. To the east of The Oaks, the soft shale slopes have not been cut into much by Mt. Hunter Rivulet, but the later uplift here has only affected the country for about three miles to the west of the monoclinal face. Razorback Range, also very little cut into, may have been affected by this recent uplift.

The undissected character of this edge is in striking contrast to the amount of dissection which the streams immediately to the west have accomplished. Blue Gum Creek, to the south of the Grose is, for instance, perched on the top of the fold. A few miles to the west, Linden and Wentworth Creeks have trenched the plateau deeply right to their heads.

The western side of the Glenbrook anticline is also undissected. The river gravels scattered over the surface of Lapstone Hill, and also on the hilltops of Wallacia, are recent deposits. These loosely-cemented, or uncemented deposits cannot remain long on the hillsides, as they disintegrate rapidly, and are washed away. They cannot be compared, in point of age, with the Kanimbla Valley, or even with the lower valleys of the Cox and Wollondilly. This is significant, as no notable stream change has taken place since these gravels were elevated, which was, comparatively, very recently.

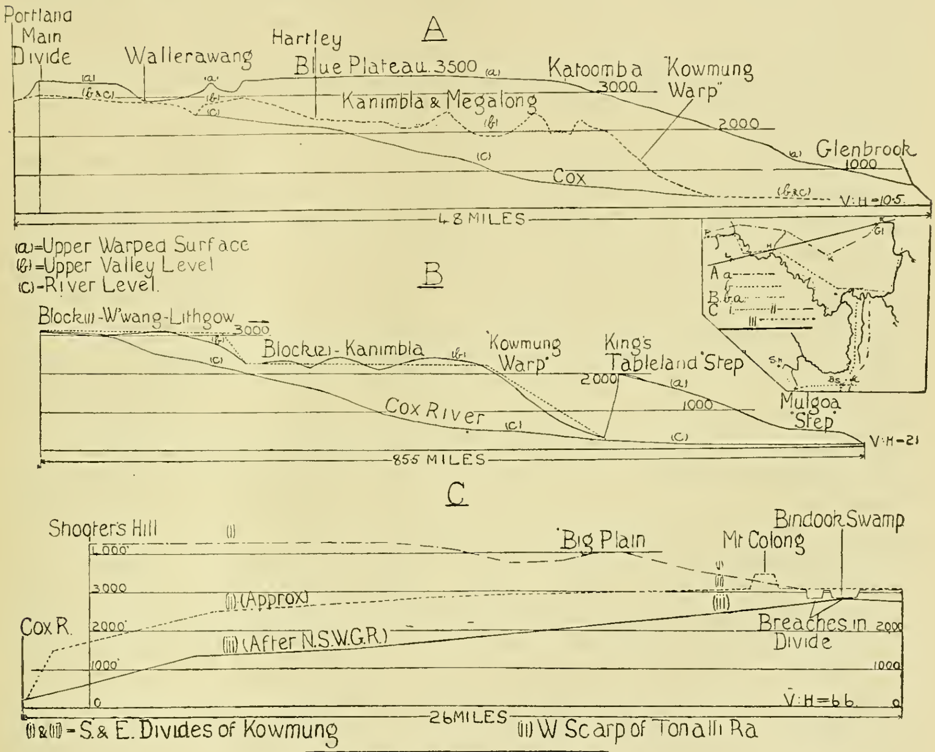
Newer Uplifts.—The Kowmung Warp.—Between the Hunter River Valley and Lake George, the age of uplift of the plateau varies regularly from north to south. The Colo River and its tributaries have cut great canyons in the hard Hawkesbury Series, right to their heads. The great mass of the Southern Plateau in the districts of Taralga, Moss Vale, Goulburn and the Upper Shoalhaven, is very little dissected. At Tallong, for instance, the uplands are flat and swampy only two miles from the Shoalhaven gorge; and there are large areas of mature valleys in the Upper Wollondilly and Abercrombie basins which have no counterpart in the Grose and Colo systems. The Cox represents an intermediate stage, where the eastern section is deeply dissected, but the western part has suffered little dissection.

The idea that the southern part of these highlands has been, in general, uplifted at a more recent time than the northern part, receives striking confirmation when a detailed examination of the topography and physiography is made.

I have applied the name "Kowmung Warp" to the warping movement which is typified by the tilted plain of the main Kowmung Valley between the Cox River and the Kowmung-Wollondilly divide between Mts. Colong and Shivering. The characteristics of this surface are shown clearly in Text-fig. 9.

Two lines of evidence—geological and physiographic—go to prove that the whole surface comprised in the valley floor which stretches from Mt. Solitary in the north to the Kowmung-Wollondilly divide in the south is a warped surface. The Kowmung Valley, part only of which is occupied by the Kowmung River system, rises southwards in a gentle, almost unbroken, slope. To the west of Jamieson's Creek, a similar ramp leads up to the Kanimbla levels near Mt. Mouin, and the Gangerang Range. These slopes, which are very even, are trenched by the great gorges of the Cox and Kowmung, but these gorges occupy a relatively small part of the valley floor. This ramp, or upper valley surface, could not have been cut at its present elevation above base-level. It is clearly an old plane, or surface of erosion, which has recently been uplifted and trenched by juvenile canyons. That this uplift is recent is shown by the fact that streams rising near the base of Mt. Mouin, and flowing south and east to the Cox, have not cut down much, and are merely nibbling away the edges of the Cox gorge. The more powerful streams, such as the Cox and Kowmung Rivers, Cedar Creek and, to the west, Breakfast and Kanangra Creeks, have graded their channels, but still flow in extremely narrow gorges. Black Hollow Creek is not much entrenched in the surface, and the shale beds leading down from Kiaramba Ridge to the Cox near Black Hollow Creek are almost undissected.

The evidence offered by Jamieson's Creek very definitely confirms this idea of warping, and is of the utmost value as a positive proof of the nature and recency of the warping. The relationship of the valleys to the tilted plain is clearly shown in Text-fig. 12. Thus Kanimbla-Megalong Valley bears the same relationship to Jamieson's Valley as the Wallerawang levels bear to the Kanimbla. In either case a flexure separates the valleys. The other evidence in the matter is more geological in character.



Text-fig. 12.—The Relationship between the Plateaux and Valleys of the Area. (A) shows the parallelism of the valley levels of the Cox with the plateau surface. Comparison is possible by projecting the two section lines of unequal lengths (broken lines) on to a straight line of uniform direction, thus giving the components of the various slopes, and hence the amount of folding in the given direction. (B) shows the two flexures in the former co-extensive valley levels, and their influence on the grade of the Cox River. (C) illustrates the effect of the Kowmung Warp on the plateau and the valley floor, and the rise up to the high Jenolan Plateau from the Blue Plateau level. Graph (i) is perpendicular to (ii) and (iii), and intersects them at Bindook Swamp. These figures constitute a deductive proof of the folding theories of this paper.

The deformation due to late warping is clearly shown by the Upper Marine sandstones between Jamieson's Creek and Mt. Mouin. These beds rise at the rate of 280 feet to the mile into Megalong Gap, and present an almost unbroken surface, very similar to that of the Hawkesbury sandstones of the Blue Plateau. An area of relative depression exists between the foot of the Mt. Solitary talus and Mt. Mouin (Text-fig. 9*B*) to the south-west. Here there is a marked change in the

slope of the sandstone. To the east, and under Mt. Solitary, the beds are sub-horizontal; to the west, they rise at the rate of 280 feet per mile—a slope far greater than that of the corresponding part of the Blue Plateau between Wentworth Falls and the Marked Tree (beyond Katoomba) which is of the order of 130 feet per mile, or the 170 feet to the mile rise of the Upper Coal Measures between Woodford and Katoomba. These, it may be noted, are maximum slopes. To the north of Megalong Gap, the series is sub-horizontal to Hartley, to the north of which there is a step up of the order of 500 feet to the Lithgow-Wallerawang levels. Cedar Creek, to the south-west of Mt. Solitary, flows along the north-eastern margin of the steep slope leading up to Mt. Mouin and its slight, uniform gradient in a gorge up to 600 feet deep, distinguishes it from Jamieson's Creek, the mouth of which only has been affected by the warping (Text-fig. 12*A*).

It is highly probable that the bedding planes of the sandstones are not parallel to the general warped surface, since the thickness of the beds varies considerably within small areas, the warped surface of erosion in such parts apparently cutting across the bedding planes. This variation is well marked to the west of Jamieson's Creek. At the junction of this stream with the Cox, the Upper Marine beds have a thickness of 300-400 feet. Below Cedar Creek, the river flows through a breached anticline of intensely hard metamorphic Devonian rock which here outcrops on the warped slope on either side of the river, being obscured to the east and west, away from the stream, by the newer sandstone. Still further up the river, the sandstones form a capping, up to 200 feet thick, on the highly-inclined Devonian beds. A notable thickening to a maximum of 450 feet is observed in the neighbourhood of Megalong Gap and Mt. Mouin. Three miles north of the Gap, on the same level, granite is exposed on the valley floor, capped in places with a thin layer of sandstone and conglomerate. Again, erosion appears to have taken place across the bedding planes.

These Upper Marine beds are found right along Kiaramba Ridge, on the eastern side of the Kowmung River, and outcrop near Mt. Colong, on part of the Kowmung-Wollondilly divide. Towards the head of the main Kowmung Valley, highly-inclined Silurian rocks, which contain the Colong Caves, outcrop on the upper valley floor, and their bevelled edges form part of the general warp slope. Other ridges on the western side of the Kowmung—Gingra, for instance, which leads down from Kanangra Walls—are level benches, part of this valley being cut in tilted Devonian strata. Near the junction of the Kowmung and Cox, the tilted surface is prominent on both sides of the Kowmung.

This main valley, eight miles wide, is hardly scarred by Black Hollow Creek, but the great canyon of the Kowmung is prominent. After passing the gap in the Cox divide near the end of Kiaramba Ridge, which is only 800 feet above the Cox, the river pursues an antecedent course, flowing into the highlands, and joining the Cox in an upstream direction in a gorge 2,000 feet deep. The gradual slope down to the Cox on the east of this part of the Kowmung Valley is unbroken by large gullies, although it consists largely of soft shales. There are also relics of mature valleys on the Kowmung-Wollondilly divide which are treated later. In passing, it may be noted that Byrne's Gap, to the east of Mt. Colong, may once have been occupied by a stream flowing northwards from the present Tonalli River area into the Kowmung.

An assumption that these great valleys were formed as a result of differential erosion in hard and soft strata is not justifiable, not only on account of the

evidence given above, but also because it would imply that weak streams, such as Black Hollow Creek, were capable of great lateral erosion after rejuvenation, but before doing much down cutting; and also because the rocks which were eroded to form this valley were hard, being Hawkesbury sandstones, Upper Coal Measure and Upper Marine Series, which were all littoral deposits. The really soft rocks of the area lie on the Kowmung-Wollondilly divide, between Bindook Swamp and Mt. Werong, which are highland areas. It is interesting to note that similar theories of sharp local warping are being advocated by Mr. Sussmilch for the Upper Hunter basin.

The Extent and External Relationships of the Kowmung Warp.—So far, field evidence has been advanced which has shown, *inter alia*, that Wallerawang, Kanimbla, Megalong, Jamieson's and the Kowmung Valleys were once coextensive and have been subjected to differential uplift, so that they are now separated by sharp flexures. It is possible to correlate these valley levels, and the earth movements producing them, with the levels and movements which produced the present Blue Plateau. Text-fig. 12*A*, which is based on simple mathematical projection of broken lines on a fixed line—the latter joining Glenbrook and Mt. Lambie, and running in a W.N.W. and E.S.E. direction—shows the relationship between the two. Each curve gives the component of the slope along fixed lines in the constant direction, and thus shows the folding movements of each line in that direction, which latter is generally taken to be the average slope of the Blue Plateau Monocline, and is certainly perpendicular to the Kurrajong-Glenbrook-Mittagong fold.

Proceeding eastwards from the Main Divide it is seen that the Piper's Flat-Wallerawang Valley is subparallel to the plateau surface, the latter being intersected by the valley of Cox's Creek. A kink in the plateau surface corresponds to a kink in the valley curve, and indicates a relative downthrow area. The Hartley flexure has no exact counterpart on the plateau surface, although the high ridges at Clarence (not shown) are possibly related. The Kanimbla-Megalong levels are parallel to the main plateau. The curve of the Kowmung Warp between Mt. Mouin and Jamieson's Creek is distinctly related to the curve of the plateau between Woodford and Katoomba. Below Jamieson's Creek the old distinctive valley levels end. It is seen that the profiles of the upper valley levels and of the plateau are distinctly sympathetic. When one considers that the warping and faulting of the Jenolan Plateau have taken place not far to the west of these valleys, the correlation is still more striking. Obviously, the earth movements which produced the flexures in the valley floor also affected the plateau surface, or, in other words, since the curves show such a striking sympathy of contour, they were produced by the same earth movements; that is, the valley levels are older than the more recent flexing movements. The nature of the original folds which produced the surface in which the valleys were originally incised will be shown later.

This piece of correlation also throws light on the extent of the Kowmung Warp, since this warp is clearly shown on the present plateau surface, the eastern edge extending across the country between Katoomba and Wentworth Falls, by Mts. Hay, Tomah and Irvine, and apparently dying out gradually to the north. A definite scarp exists along this line. One result of this is to give Katoomba an average annual rainfall of 56 inches, whereas, without the scarp, the rainfall would probably not exceed 40 inches.

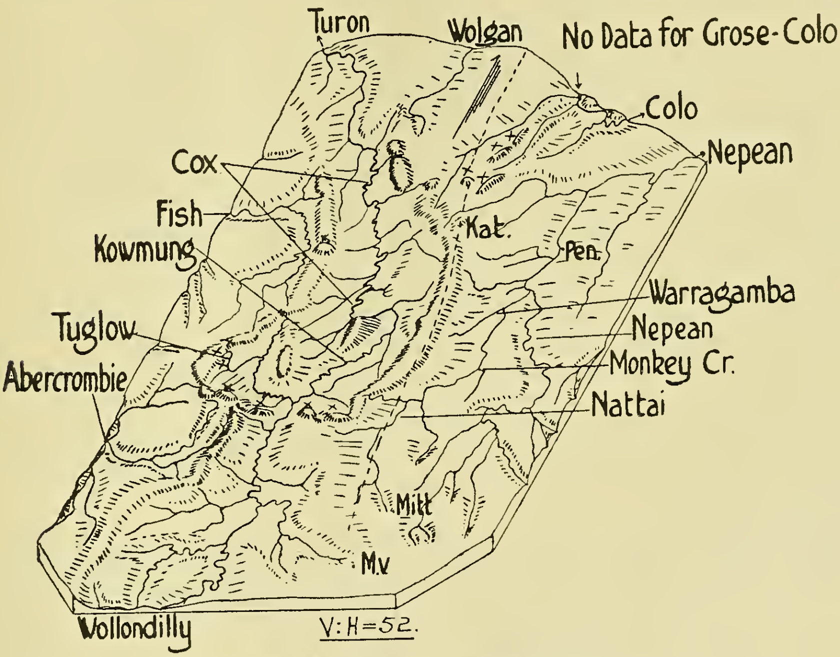
The warping may also be correlated with the Nepean Ramp, extending southwards from the neighbourhood of Sydney towards the Shoalhaven River. The edge of this warp is not perpendicular to the general north-south line of the monocline, but runs to the south-west from (near) Sydney to Picton, where the Razorback Range, at the point where this warp crosses the monocline, is probably a fault block.

To the north-west, the hinge is somewhat indefinite towards Oakdale, owing to the flattening of the warp and great erosion in the soft shales by tributaries of the Nepean, but the southern rise is plainly shown on both sides of the Burragorang Valley. To the west of Burragorang, the uplift appears to have been more intense, as the plateau to the west at 3,100 feet is 600 feet higher than the plateau to the east of this valley at 2,500 feet. It is extremely probable that this part of the valley of the Wollondilly has been excavated along a fault line, the valleys of Lacy's and Green Wattle Creeks probably following smaller faults. I hope to discuss this matter fully in a future paper on the Wollondilly Basin.

On the east of Burragorang, there is a rise of 400 feet on the plateau from the Warragamba to the Nattai Valley, a distance of seven miles. To the west, the long ridges between the Wollondilly and Black Hollow Creek rise from 1,900 feet in the vicinity of the Cox to an average of 3,100 feet on the plateau around Mt. Colong over a distance of nineteen miles (Text-fig. 12*C*), giving an average slope of 63 feet per mile. The rise of Kiaramba Ridge from the Cox to Bindook Swamp on the Kowmung-Wollondilly divide is 2,500 feet (all of which is not due to warping, although most is) over a distance of 23 miles, giving an average slope of the order of 119 feet per mile. Thus there is a regular change of slope along the lines perpendicular to the edge of the warp as one moves from the east of Burragorang to the north of Jamieson's Creek. The average mean slopes are of the order, in feet per mile, of: Plateau from the Warragamba to the Nattai, 59; plateau between the Cox and Bindook Creek, 63 (Text-fig. 12*C*); Kiaramba Ridge in the Kowmung Valley, 109; upper valley slope from Jamieson's Creek to Megalong Gap, 280; plateau between Wentworth Falls and Katoomba, 140 feet. It will thus be seen that the warping reached a maximum of intensity to the north-east of Gangerang Range. To the west and south-west of Gangerang, the movement of uplift became so intense that faulting took place, as we have seen in the study of the Kanangra Platform. The Nepean Ramp-Kowmung Warp thus has the general form of a plunging syncline. It will be noted that the greatest thickness of Permian and Triassic rocks lies at the focus of the northern edge of this syncline; that is, the old Permian and Triassic geosyncline has been revived and intensified by late warping movements.

The latest uplift of Jenolan Plateau, which differentiates it from the main Blue Plateau, has already been discussed. A well-marked warp runs from the western side of Mt. Lambie to the north of Rydal, and thence on the western side of Kanimbla Valley between the Cox River and the main Divide. This warp has also affected the eastern part of Megalong Valley to the south of Megalong Creek. Still further south, it passes into a fault, which begins near the junction of the Cox and Kanangra Rivers and runs parallel to the latter. Indeed, the course of this stream and its great canyon have been determined by this fault. Continuing to the south of Kanangra Walls, the fault becomes indistinct in the soft rocks of the Kowmung-Wollondilly divide, but appears to continue into the Wollondilly Basin, and to be connected with the Lake George fault system. I hope to discuss this matter in a later paper.

The physiographic fault at Hartley is, I think, not nearly so extensive as this other fault on the west of the Kowmung. Apparently the main warp some five miles to the north of Hampton bifurcates, one branch continuing in a less intense form to the north, towards Mt. Lambie, the other branch going to the north-east across the mouth of Lowther Creek, where it is probably responsible for Blaxland's Swamp, and continuing to the west of Hartley, and for some distance to the north of the high ridge at Mt. Clarence (up to 4,000 feet). The kink in the plateau and upper valley surfaces near Lithgow appears to be a part of this earth ripple. In the foregoing discussion, the existence of older folds has been kept in the background. Having determined and localized the newer earth movements, it is now possible to identify the older folds.



Text-fig. 13.—Pre-uplift Peneplain Surface.

Primitive folds and basalt residuals are found in meridional lines, with a different stream arrangement from that obtaining at the present time. The broken line shows the crest of the first extensive fold, which was an anticline.

The Old Blue (Mt.) Anticline.—The existence of a monoclinal fold in the vicinity of Kurrajong and Glenbrook was proved by David. At Kurrajong Heights, a maximum vertical displacement of 1,900 feet has been caused by folding and faulting. Near Glenbrook, the amount of uplift varies from 600 to 800 feet. As the fold between Kurrajong Heights and Bent's Basin is composed of hard sandstone, and is of recent formation, it is well preserved. That this fold continues to the south is clearly shown by sections of Wianamatta shale near The Oaks and at Mowbray Park, between Picton and the Nattai River. To the west, the shale is sub-horizontal, but it dips sharply to the east on to the flat country near Camden and the more elevated land in the vicinity of Picton.

To the south of Picton and the west of the Nepean River there is a definite dip of the land surface to the east, as the railway heights indicate. The more easterly new line through Bargo is, on the average, 150 feet lower than the older line to the west, through Picton Lakes and Balmoral. At Mittagong, the monoclinal fold again appears to be present, rising 500 feet above the plain. Mt. Alexander, to the north of the town, is composed of sandstones which dip to the south at an angle of 11°, according to Taylor. This dip would be sufficient to account for the vertical displacement of 500 feet without faulting, although it is probable that both folding and faulting are involved. Still further to the south, the monocline as a distinctive topographic feature appears to die out. The southern portion of the fold is superimposed on the Kowmung Warp and the Nepean Ramp. It has already been shown that, between Picton and Kurrajong Heights, the face of this monocline is of recent development. The old eastern face of the main Blue Plateau uplifts was from three to six miles to the west, and the fold had a much more uniform slope at its base, as the Mulgoa Step had not been formed. From Razorback southwards, however, it is probable that the original fold face is preserved. The nature and extent of the first folding movement may be determined by subtracting the later movements from the sum total. This is readily done by reducing the Kowmung-Kanimbla-Wallerawang Valleys to their original level. We have already seen that all of these valley floors were, in the past, co-extensive. By flattening out the later flexures, therefore, the original contour of what is now the plateau surface will be obtained, as in Text-fig. 14.

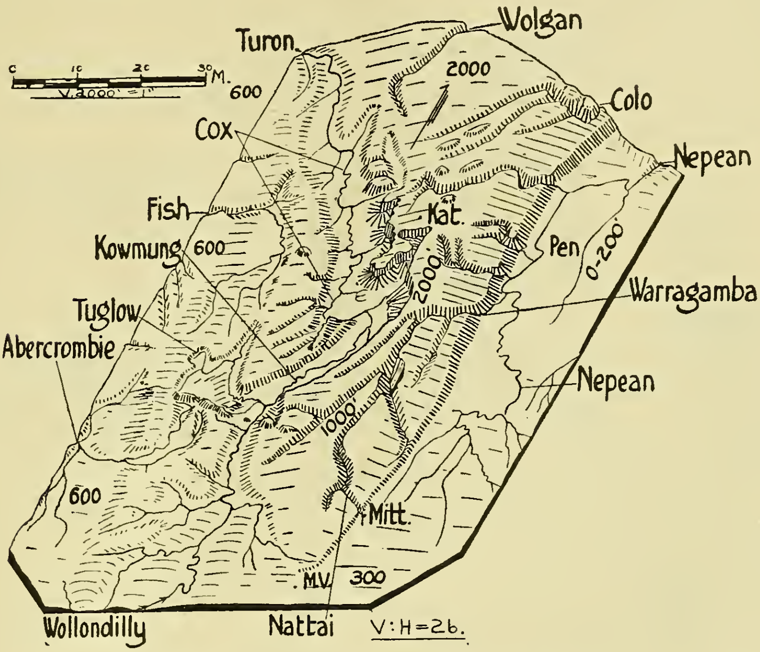
At Wallerawang, the plateau surface was 600 feet above the local base-level of erosion (*not* 600 feet above sea-level); Kanimbla Valley was entrenched 1,200 feet in the plateau surface, Jamieson's Valley, 1,500 feet, and the Kowmung Valley from 1,400 feet at the Cox junction to 400 feet at Bindook Swamp. Thus the surface takes the form of an asymmetric anticline (Text-fig. 14), with a steep eastern limb and a gently sloping western limb. It attained a maximum elevation of 2,000 feet along the Bilpin-Hazelbrook-King's Tableland line, which step continued across the present Lower Cox Valley, and is still found to the east of Burragorang Valley.

If a hinge or line of folding were developed along some part of an asymmetric anticline, near the crest, and the limb of the original fold away from the hinge and the crest were uplifted, then that part of the fold adjacent to the original crest of the anticline, and along the new hinge, would be rather flattened, that is, its curvature would be decreased. That is to say, there would be a change of slope—or "step"—in the final fold curve near the position of the crest of the original anticline.

That such a position has arisen in this region is shown by the topography of the plateau surface. The land near the crest of the old anticlinal fold is now represented by the Bilpin-Hazelbrook-King's Tableland step at 2,200 feet. That this step was the crest of the old fold is clearly shown by the decreasing depth of the upper valleys as one goes to the west (Text-fig. 12), and by the still-existing uniform slope to the east. This theory has four specific advantages:—

1. It explains the erosion of the great Jamieson's Valley almost to the Grose Divide, and the formation of the Lower Cox and the Burragorang Valleys. All of these are located on, or near, the supposed anticlinal crest, which would be the main line of weakness and erosion. The continuous and almost straight line of these valleys is most striking. It is also notable that the Kowmung Valley is not included in this system.

2. It also explains the peculiar topography of the King's Tableland, which can only be mentioned briefly here. A number of small streams rise on this step and flow westwards into Jamieson's Valley, rising in broad, swampy mature valleys between 1,800 and 2,000 feet. They plunge into the higher land from



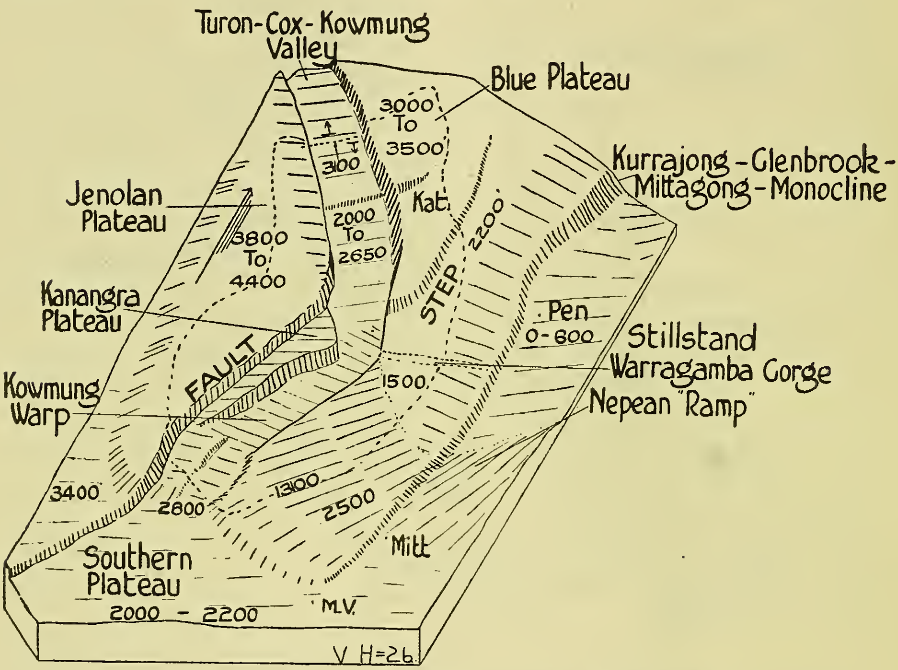
Text-fig. 14.—The Old Blue Mountain Anticline.
The old anticline had a steep eastern face, but sloped gently to the west. The heights given *are above the local base levels of the respective districts.* The elevation of the western portion (marked 600 feet) was probably of the order of 1,000 feet above modern sea-level. The central heights are approximately correct on both standards, as are the eastern.

2,200 to 2,300 feet before entering the valley, flowing through narrow little gorges. They appear to be antecedent, and their swamps may have formed by the partial blocking of the streams caused by a slowly-rising barrier to the west—the newer fold, or Kowmung Warp. I hope to discuss this more fully in a future short paper.

3. The formation of the Nattai Valley is explained. At the present time the Nattai is a misfit, trickling over the floor of a big valley. The cliff walls are much cut up and dissected, in strong contrast to the straight, new cliffs of Burragorang. As the Nattai shows small meanders such as are not found on the lower Wollondilly, its valley is also older. This agrees with the previous conclusion that the latter is a recently-formed stream, its position being determined by the location of the old anticlinal crest. This point will be further discussed later.

4. Such a fold as is postulated in Text-fig. 14 accounts for the very extensive dissection of the hard rocks which has been accomplished by Erskine, Glenbrook and Euroka Creeks, the Grose River and its tributaries, the Colo system and the

Nattai. The country which was more affected by the later warping and folding, although now more elevated, has not suffered anything like the same degree of dissection. Again, the newly-raised Nepean Ramp and the Southern Tablelands around Goulburn are comparatively little dissected. In general, the mature valley systems (Kanimbla, etc.), which have been described, fit in very well with this theory.



Text-fig. 15.—Analysis of the Fold Systems (generalized).
The principal modern tectonic features of the region are here summarized. Overlapping of folds gives greater elevation, so the most elevated part (Jenolan Plateau) has undergone three uplifts. The superposition of the old anticline on the Kowmung Warp, and its effect on the altitude of that part of the region are shown. This is an extension and generalization of Text-fig. 2.
Scale: 1 inch = 30 miles. Cox divide shown thus - - - - - -.

Text-figs. 13, 14 and 15 show the whole process of folding which the Cox Basin has undergone. Text-fig. 13 is further discussed later. Text-fig. 14 is a restoration of the old anticline, based on the data shown in Text-fig. 12, whilst Text-fig. 15 shows the principal modern features of the topography, and summarizes the conclusions as to the nature of the post-basaltic earth movements which have affected this area. The northern edge of the warping and folding movements which uplifted the southern highlands of this State is represented by the Kowmung Warp. The southern edge of the main northern uplift is represented by the Hornsby Warp across the Hawkesbury, and the old anticline.

Direction of Forces Causing Uplift.—Whilst it is very unsafe to base any very general conclusions as to the direction of forces causing these uplifts on the evidence offered here alone, a few suggestions might not be out of place. There

is, I think, very little evidence to justify the possible suggestion that the uplift of this region is largely the result of purely compressive (tangential) forces. On account of the general low angular value of the warping movements, the absence of great overthrust faults, and the formation of purely plateau topography, the forces of uplift would appear to have been, in the main, normal to the surface of the earth. This would involve a certain amount of compression, as two normal forces at different points would give rise to a certain resultant tangential force. It has been suggested that the uplift of this plateau was the result of forces acting from the Pacific. Alternatively, another opinion has been expressed that the later phases of uplift were largely caused by forces from the west. A tentative conclusion might be, that the principal uplifts were the result of normal forces, and the tangential forces which they set up acted mainly from the west, although forces acting from the east were not unknown.

Streams of the Area.

Stream Characteristics and Relationships.—The general characteristics of the streams of Eastern Australia have been outlined by Taylor (Physiography of E. Australia), who has discussed many specific anomalies of flow. These streams fall into two main classes—longitudinal and transverse. The first class includes many of the tributaries of the Upper Murrumbidgee, the greater part of the Wollondilly, Shoalhaven and Nepean, the Upper Cox and some streams of the Upper Hunter. Such streams as the lower parts of the Clyde, Shoalhaven and Hawkesbury, the Upper Abercrombie and Turon, the Grose, Colo, Goulburn and Lower Hunter Rivers may all be classed as transverse streams. In general, each main river system includes many streams of each type, but the highly irregular, meandering courses throughout their lengths of the composite rivers give evidence that the present anomalous arrangement is, in general, of some age.

In the Cox Basin itself the streams fall naturally into two classes, according to geographic distribution. Those in the western part of the area, such as the Cox above Jamieson's Creek, the Kowmung, Tuglow, Upper Wollondilly Rivers and many smaller streams flow in highly irregular meandering courses (Text-figs. 4 and 8), although, for the most part, they are now entrenched in deep canyons. These meanders have been inherited from earlier cycles. The eastern streams, such as the Lower Wollondilly, Warragamba, Lower Cox and, a little to the north, Erskine Creek and Grose River, do not show meanders. They are generally straight, with bends and curves of low angular value. In fact the main river—the Warragamba—is absolutely straight for nine miles of its fifteen-mile course. These streams are quite different from, and of much more recent formation than, those of the first-mentioned class, which show structural affinities with the ancient rivers of the Western Slopes, the Macquarie and Abercrombie. On these grounds one might reasonably believe that the Western Cox Basin once belonged to the Western stream system.

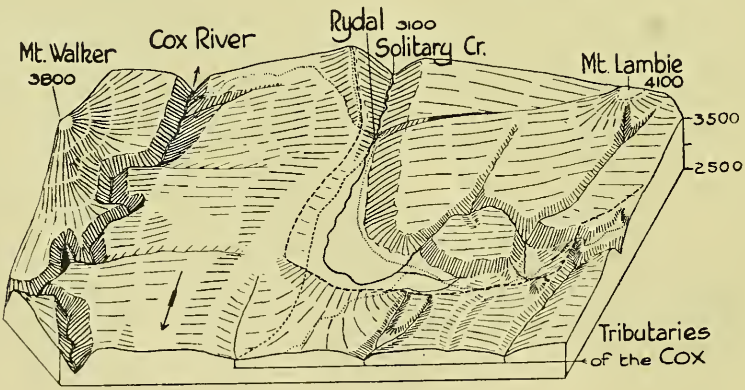
The Cox River Basin occupies an oval-shaped area at the centre of a radial drainage system. Many of the main streams of east-central New South Wales rise on the Cox watershed. They include the Grose and Colo Rivers, the Turon, Campbell and Fish Rivers of the Macquarie system, the Abercrombie River, and tributaries of the Wollondilly and Nepean. At first glance it might be thought that the Cox is a simple consequent stream, whose origin is directly traceable to the uplift of the Blue Plateau and which has eroded its present complicated series of canyons directly in that surface, enlarging itself at the expense of surrounding

streams. Field evidence is quite against this, as the Upper Cox itself is threatened with capture in places, and that part of its basin is in a state of siege.

Divides of the Cox.—In places where the original plateau surface is well preserved, such as Katoomba, Hampton, Shooter's Hill, and King's Tableland, the divide is comparatively wide and flat. It is the remains of an ancient peneplain, dissected to a depth of 200 feet by mature valleys, the direction of short streams being largely determined by local geological structure. To the north and north-east of Lithgow, for example, the influence of two perpendicular sets of master joints has given the streams a trellis pattern. The small cores of undissected country on the eastern and southern divides are being attacked by steep streams on either side of the watershed. At some places local captures are pending, as Wentworth Falls (Taylor), and also near Mt. Werong, where Werong Creek, of the Kowmung system, has captured part of the head of the Abercrombie on an ancient plain.

The Main Divide between Rydal and Jenolan is a high ridge flanked on either side by sub-mature valleys. Here there is no prospect of any marked stream readjustment.

In other places the divide is very unstable. At Wolgan Gap it has been breached, and Cox's Creek rises above a yawning valley in which the Wolgan River flows, 1,200 feet below. Capture of the high stream has proceeded to some



Text-fig. 16.—Solitary Creek.

Note the high-level valley of the Creek, and the steep canyon of the Cox. The high-level valley of the Cox between Rydal and Mt. Walker is shown, and the meanders of the Cox. Solitary Creek is on the point of capture. Note the small antecedent tributary on the west in the diagram. Scale: 1 inch = 2 miles.

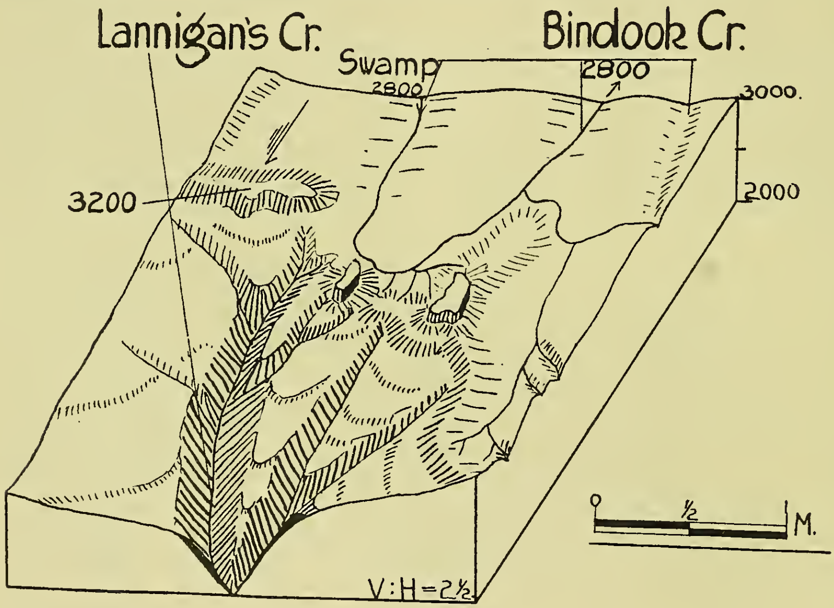
extent. Again, at Piper's Flat the Main Divide is represented by a ridge which rises forty feet above the plain, and is about a quarter of a mile wide. This runs across a valley four miles wide and 400 feet deep, and appears to be a local fold in shale. On the northern side Dulhunty's Creek, a tributary of Williewa Creek (Turon), is flowing at a lower level than Piper's Flat Creek, and with a steeper grade—100 feet per mile as against 30 feet. It is cutting back in the soft ridge, and threatening to capture Piper's Flat Creek. A few miles to the north the head of Gow's Creek, flowing in a broad valley at 3,500 feet, is being captured by a

small tributary of Solitary Creek. Here a slight change only is involved. Two great breaches in the western divides, at Rydal and Bindook Swamp, call for special attention.

Solitary Creek.—Solitary Creek (Text-figs. 4 and 16) rises on the northern side of Mt. Lambie and, turning, flows southwards through Rydal and later, with the Fish River, pursues a westward course through Bathurst, thus forming part of a spiral. Between the Lambie block and Mt. Walker the upper valley surface of the Cox is prominent at 3,100 feet, stretching south to the scarp near Hartley. Immediately to the south-west of Solitary Creek Plain between Wallerawang and Rydal, a continuous scarp rises, which is a continuation of the Western Kanimbla Warp. A small tributary of Solitary Creek flows into the warp (right centre, Text-fig. 16), whilst a little lower down Solitary Creek flows across the warp line on to a plain, re-entering the higher scarp just above Rydal. Six hundred feet below, and only two miles away, the Cox flows in a juvenile gorge sawn in tremendously hard quartzite, whilst steep tributaries are threatening to capture Solitary Creek from the east and north. Immediately to the north of Rydal the Main Divide is only half a mile from the creek, and fifteen feet above it, the valley, along which the Western Railway runs, being quite continuous. The Cox shows very fine meanders in extremely hard rock, and so must have followed its present course before the cutting of its modern trench. On the other hand, it is not possible that Solitary Creek should have maintained its present relative course for long, since tributaries of Piper's Flat Creek, but slightly rejuvenated, are in the course of capturing it. The presence of the continuous Wallerawang-Rydal Valley and the boathook bend of Solitary Creek, together with the age and power of the main river, show that some stream change has taken place. A reconstruction of the topography when the Wallerawang and Kanimbla levels were co-extensive is instructive. Then the Cox flowed sluggishly over the plain floor of its valley. The local "kink" in the valley floor and the plateau near Wallerawang (Text-fig. 12) could not then have existed, as it is lower in the valley than the contemporaneous valley levels on all sides at 3,000 to 3,200 feet. At that time Solitary and Piper's Flat Creeks, and the Main Divide at Piper's Flat were on much the same level. Later, probably in conjunction with the fault at Hartley, the area around Wallerawang lagged behind a little in the continuous uplift, forming a small tectonic hollow. Uplift and tilting of the Wallerawang Valley took place towards the west and south-west. Piper's Flat now has a grade of 30 feet per mile, and is being eroded. Experience shows that streams—e.g., the Lower Cox and Wollondilly—erode previously deposited alluvials when flowing at a grade of only ten feet per mile. Piper's Flat, now being eroded, could not have been formed at its present slope. At the same time, the Cox could not have readily captured Solitary Creek, as it had not then its present advantage of grade. But to suppose that Solitary Creek at that time flowed as it does now, leaves unexplained the great Wallerawang-Rydal Valley, which is quite dissimilar to other valleys of tributary streams just to the west, and has been carved in hard conglomerate and quartzite by stream action. Also, the anomalies of the present Main Divide—here partly valley, partly slope divide—are not explained.

On account of the permanence of the Cox, one is forced to the conclusion that a stream once occupied Wallerawang-Rydal Valley, and flowed from Rydal to the Cox. This would place the Main Divide near Tarana, and might include Antonio's Creek, which runs northward into Solitary Creek and parallel to the Main Divide, in the Cox system. This old Divide would have passed in a normal

manner over Mt. Lambie, and would have consisted of very soft, decomposed granite, similar to that at Sodwalls. After the inception of the present topography, but before the sagging around Wallerawang, the Fish River and its tributaries, tearing back through the soft granite, captured Solitary Creek near Tarana. Then the Cox, being rejuvenated in this part, cut back past Mt. Walker, and the slight sagging around Wallerawang gave the small tributaries of Piper's Flat Creek a higher grade than previously, so that now Solitary Creek, entrenching slowly, is threatened with recapture by the Cox. The thalweg of Solitary Creek below Rydal supports this theory. The head of entrenchment is at Rydal. The grade from here to Tarana (12 miles) is 50 feet per mile, whilst from Tarana to Bathurst, Fish River has only a grade of 11 feet per mile. The steepest portion, between Rydal and Sodwalls, just above Antonio's Creek, has a grade of 70 feet



Text-fig. 17.—The Breached Divide at Bindook Swamp.
Lannigan's Creek is on the point of capturing the high-level swamps. Note the erratic course of Bindook Creek, and the sandstone residuals in a late mature valley.

per mile. Considering these figures, and the softness of the decomposed granite, one concludes that the tributary of Fish River, flowing at a low level, was quite competent to capture Solitary Creek from the Cox when the latter was at a standstill. Rejuvenation has since moved upstream from the supposed ancient divide. Thus Cox River is now about to recapture Solitary Creek.

Bindook Swamp.—Bindook Swamp lies on the Kowmung-Wollondilly divide four miles south-west of Mt. Colong. The swamp lies in a great level valley, 2,800 feet above the sea, to the east and west of which the plateau rises to an elevation of 3,200 feet, and is cut in sandstone (horizontal) and slate (Text-fig. 17). Two isolated sandstone hills are left in the valley, which is cut in very soft Silurian

strata. Bindook Creek flows north over a level valley to within a couple of hundred yards of the divide, which is only a few feet above the stream and is absolutely flat. It then turns south, and flows to the Wollondilly. This condition of affairs is obviously transient, as Lannigan's Creek is on the point of capturing Bindook Creek. The gap in the divide is three-quarters of a mile wide, and the valley of which it is part is mature to late mature in type. It forms a link between the Kowmung Valley on the north and the Wollondilly Valley on the south. It represents at present an air gap in the divide formed by stream erosion. The relationship of this to the Kowmung and Wollondilly is discussed later.

Cox River and its Tributaries.

Relative Stream Ages.—The general classification of streams into a newer and an older type has already been mentioned. This classification would, however, fall to the ground if ancient streams following meandering courses were to assume meandering courses subsequent to uplift and rejuvenation. But such ancient streams will continue to enlarge their meanders after rejuvenation, as tangential horizontal forces still act at the bends, eroding on the convex stream bends and causing the channel to migrate. Fine examples of these meanders enlarged by a revived stream flowing down a warp are observed on the Cox near Jamieson's Creek. The long straight courses of the Lower Wollondilly and the Warragamba especially, which are consequent streams, and the straight character of their gorges, with a slight overlapping of spurs, indicate that they are certainly newly-formed streams. Many similarly revived streams in this region—the Colo and Macdonald, for example—have preserved fine meanders, and it does not seem reasonable to suppose that such a straight stream as the Warragamba, flowing under exactly similar conditions to the Colo and Macdonald, could have divested itself of all traces of antiquity since uplift. It will be seen that these newer streams are confined to deep valleys and gorges on the eastern side of the Cox Basin.

The great valleys of the Kowmung and Cox, from eight to fifteen miles wide, are occupied by ancient streams. The meanders and horseshoe bends of these streams are not local features, but are found in all varieties of rock types, including horizontal and tilted shale and sandstone, highly-inclined slate and quartzite, and porphyry and granite. The amplitude of the bends varies inversely as the hardness of the rocks in which they occur, but the actual type and character do not change.

The actual form of the valleys of such streams as the Lower Wollondilly and Green Wattle Creek suggests that they are of recent formation. For mile after mile the sandstone cliffs flanking the eastern sides of parts of these valleys are absolutely straight, and are known as Burragorang and Green Wattle "Walls" respectively. They are hardly notched at the top and show no embayments. No tributary streams come over these cliffs to the main streams below. The cliffs of Jamieson's and Grose Valleys are deeply embayed on all sides, and deeply notched at close intervals, even where mere wet-weather streams cross them. These walls are, generally, less than a mile from the river, as close as are the cliffs of the Grose to their river. This would seem to indicate that these walls and the valleys which they flank are of very recent development. For a few miles on the western side of the Wollondilly around Byrne's Creek and Tonalli River much more erosion has been accomplished, but this may have been initiated by streams

flowing westward through the present air gaps near Yerranderie to the Kowmung. The levels of the passes seem to indicate this.

In the case of the Lower Cox Valley, the river above King's Tableland shows characteristic meanders, but downstream these do not appear. Just where the river crosses the King's Tableland-Tonalli scarp a great double "S" bend has been developed on a small unwarped plain just above the scarp. This feature is of recent origin, and is quite different from other Cox meanders, not being fully developed.

The Kowmung-Jamieson's Valley stretches from Wentworth Falls to Bindook, and from King's Tableland to Gangerang Range, having a north-south length of 30 miles and an east-west width of eight miles. The eastern outlet is a gap in the rocky walls less than a mile and a half wide. As the Kowmung Valley has been cut in a series of rocks similar to, although somewhat harder than, those of the Lower Cox Valley, an explanation by differential erosion, particularly in the light of the warping indicated, is out of the question. Also the Cox Valley below this point is quite juvenile. Even the overlapping spurs are preserved. The Lower Wollondilly has every appearance of having developed along a fracture or fault of a linear character. This is not the case with the Nattai, which has a rather tremulous appearance, and is probably an old stream preserving part of its original course, although part has been wiped out by newer streams. Werriberri (Monkey) Creek, which is not much entrenched on the average, and has remarkably few tributaries, also appears to be a relic of an old meridional stream which has been deprived of most of its water by newly-formed streams. Thus the Upper Wollondilly-Kowmung-Upper Cox form an old stream line, whilst the Lower Cox-Wollondilly is of much more recent formation.

Anomalies of Direction.—A survey of the Cox basin shows many anomalies in the direction of stream flow. The normally-branching type of stream is almost absent, and the whole pattern is curiously twisted. Many of the streams are subsequent, being largely determined by rock strike. Hollander's and parts of the Tuglow Rivers, Mumbedah Creek, Breakfast Creek, Marangaroo Creek and many smaller streams come under this heading. The Kowmung runs partly along the strike of the Devonian beds, and also probably follows an ancient fault. A number of the tributary streams join the Cox in an upstream direction. Lowther, Farmer's, Lett, Mumbedah, Kanangra Creeks, the Kowmung and Little Rivers are good examples. These, especially the first-named, which flows in granite, may be due to a former westward drainage. The great arc of the Hollander-Tuglow is parallel to lines of basalt residuals strung along the Kowmung-Wollondilly and Main Divides between Shooter's Hill, Oberon and Yerranderie. Residual streams flowing just along these divides are also parallel to the main arc. The basalt flows, now almost obliterated, appear to have influenced these streams, which are also parallel to the general rock strike.

The Kowmung Basin in particular is asymmetric. It receives no tributaries of note from the east, owing to the proximity of the Black Hollow Creek divide in the main upper valley. Air gaps in the Tonalli Range to the east, however, may indicate the former flow of westward streams into the Kowmung, which might also have received streams from the present area occupied by Black Hollow Creek before the last phases of uplift caused a longitudinal channel to form along the warp in the eastern part of the valley. Mature relics of valleys on the Kowmung-Black Hollow divide indicate such a possibility. The Warragamba is

also asymmetric, as its northern divide is less than four miles from the river. Parts of the Lower Wollondilly are also similar in this respect.

As the streams flow at present, boathook bends, especially that of the Tuglow-Kowmung line, are not at all rare. It is quite impossible to suggest a scheme of stream flow in the past, and post-basaltic, which would be theoretically normal and fit in with observed physiographic facts. It is considered, therefore, that this stream system has been abnormal over a considerable period of time, and its evolution has been determined by very many factors—normal erosion, geological structure, vulcanism and tectonics all having been prominent.

Relationship between the Kowmung and Wollondilly.—The remarkable breach in the divide between these two streams at Bindook Swamp has already been discussed. The asymmetry of the divide is notable, as it is nine miles from the Wollondilly and three miles only from the Kowmung. A large area of the Bindook Swamps and level valleys of the former system, extending three miles south of the divide, is in danger of imminent capture by the Kowmung.

This is the only notable gap in the divide between Mts. Colong and Werong, although numerous narrow gaps occur in the soft Silurian rocks along the divide. The gap becomes even more significant when the course of the Wollondilly is studied. At the junction of Murruin Creek—into which Bindook Creek empties itself—with the Wollondilly, the river turns through 120 degrees, forming the "Murruin Elbow," flowing eight miles in an easterly direction before resuming a northward course. The character of the river also changes at this bend. Above here it swings backwards and forwards in great meanders, which are cut in a canyon 2,000 feet deep. Below the elbow the river has few bends, these few certainly not being meanders. As in the case of the Cox, this indicates different ages for two sections of the stream. The case of the Wollondilly is the more impressive, however, because the character of the gorge does not change here, the deep, broad canyon persisting far upstream.

To the north of the divide at Bindook the ancient Kowmung flows, also sweeping past this point in a great turn. Unlike the Wollondilly it shows meanders both above and below the bend.

The conclusion is, that before the uplift of the Blue Mt. Anticline (here 400 to 600 feet), the Upper Wollondilly and the Kowmung formed a continuous stream, which was broken up by capture, giving the present arrangement. This stream line is post-basaltic in age, as it cuts across the line of old basalt residuals. Apparently at one time the basalt extended continuously along this divide. If that is so, the Upper Wollondilly, Kowmung and Cox originated in Late Tertiary times, and developed their meandering structure after the basalt flows, and before the first uplift of the old anticline.

History of the Stream System.—The conclusion has already been reached that the Kowmung, Jamieson's, Kanimbla and Wallerawang Valleys were once coextensive near base level. The conclusion that the original uplift was here of anticlinal form with the crest near the King's Tableland-Lower Wollondilly line leads one to the corollary that this great valley was cut in the western flank of the fold. The depth varies from 400 feet at Bindook Swamp to 1,500 feet near King's Tableland, gradually shallowing to 1,200 feet in Kanimbla and 500 feet near Wallerawang. The continuous valley opening out from Piper's Flat into the Turon Basin could not have been entirely eroded by the streams now occupying it (cf. Cox's Creek Valley). The line of gravels also points to the presence of a large stream, which once flowed over the present Main Divide. The evidence of

relative age of the various streams proves that the stream system had no outlet to the east. In view of all these facts, then, it appears that the Upper Wollondilly-Kowmung-Cox flowed to the north-west into the Turon before the initiation of the post-basaltic uplifts.

After the uplift of the anticline numerous consequent streams, such as Erskine Creek, Grose River and the Warragamba, were formed on its steep eastern face. These obliterated the old (feeble) drainage, leaving only a few relic streams, such as Werriberri (Monkey) Creek and the Nattai. Pushing back along joint planes, and possibly along fracture lines, these streams cut through the hard plateau sandstones and found the soft Coal Measure shales beneath, rapidly enlarging their valleys. In this way the valleys of the Lower Cox and Wollondilly, Lacy's and Green Wattle Creeks and the Nattai were formed. The valleys of the smaller streams are surprisingly large and well graded, and do not compare unfavourably as regards size with the Wollondilly Valley (Burragorang) itself. This is further evidence that the latter was not always occupied by a large stream. Thus before the initiation of the main Kowmung Warp these streams were attacking the divides of the old Kowmung line to the west.

When the Kowmung Warp commenced, the flow of the Cox was considerably retarded, as the river was pushing against the uplift. The Kowmung and Upper Wollondilly were thrust up, but were not able to cut down very much, on account of the hanging up of the Cox. Thus the low-lying Lower Wollondilly, cutting along lines of weakness, was enabled to capture the high-level, sluggish Upper Wollondilly, and to push back the new divide at the expense of the Kowmung. The Lower Cox River, which had previously almost obliterated the divide between it and Jamieson's Valley, continued this erosive work, and the middle Cox and Kowmung being quite unable to hold to a northward flow against the rapidly rising warp, were, in course of time, captured and reversed. That the Kowmung was able to keep to its original course is shown by its antecedent nature before its junction with the Cox.

During this time the flexure at Hartley had been developing, cutting the Upper Cox off from the Kanimbla streams. The Upper Cox, flowing over Piper's Flat, deposited the older gravels. Using Kanimbla Valley as a base-level of erosion, the Cox above Hartley began to trench its upper course and gradually the whole of the river was reversed. Before this took place, Upper Solitary Creek had been captured and reversed by a tributary of Fish River. The stream flowing along Piper's Flat being reversed, it began to cut into the older valley a little, forming the modern "Piper's Flat", extending from Wallerawang to the present Main Divide. A slight sagging of the crust around Wallerawang, together with some tilting towards Mt. Lambie, caused this flat to dip east, and revived the streams flowing along it, causing erosion of the flat, which is now proceeding, and allowing small tributaries to attack the valley divide of Solitary Creek.

At the head of Cox's Creek, Wolgan River, which had been considerably affected by the old anticline, had cut through the Hawkesbury Sandstone—here fairly thin—and had cut a great gorge in soft underlying Coal Measure strata. At the present time Cox's Creek is being gradually captured.

Since these various stream changes have taken place, the Upper Wollondilly has been able to cut back, and is now entrenched as far upstream as Paddy's River. Kowmung River has cut a profound canyon up to 2,000 feet deep almost to its head, and small tributaries are capturing Bindook Creek, tending to make the

divide here more symmetrical. Marked asymmetry of this divide was caused, in the first place, by the captured Upper Wollondilly being able to cut back in the old high-level valley before the Kowmung was rejuvenated to the great bend. Cox River has cut two series of great canyons, between Wallerawang and Hartley, and between Megalong and Jamieson's Creek. At the present time the stream system is in a state of neutral equilibrium, and only comparatively small captures are pending.

These conclusions have been previously arrived at, in part, by Taylor, who postulated a westward flow for the Cox-Wollondilly. This paper varies his conclusion by suggesting the Upper Wollondilly-Kowmung-Cox as the old stream line.

With regard to the streams of the Nepean system, there is no evidence that they have drained into the western rivers since the commencement of the folding which caused the Blue Mountain anticline. Such a direction of flow, as Taylor has suggested in his papers, was possible before the commencement of this series of uplifts, although I rather incline to the opinion that the Nepean, Cordeaux, Cataract and Avon are comparatively recently-formed streams of consequent type. Taylor's theory of the formation of Kanimbla Valley in the western side of the first fold is definitely established.

Past History of the Area.

a. Earth Movements.

Silurian.—Subsidence. Deposition of sedimentary rocks, since metamorphosed. Now found in western part of area as slates, claystones, limestones, etc.

Unconformity.

Devonian (Lower?).—Further subsidence. Deposition of shales, sandstones, conglomerates, etc., since largely metamorphosed to quartzites, slates, etc.

Devonian? or Carboniferous.—"Kanimbla Epoch". Great folding and mountain building movements. Intrusion of batholith of granite, with sills and dykes of quartz-porphyry. Regional metamorphism. Erosion.

Carboniferous.—Great cycle of erosion. Granite exposed and a peneplain formed.

Great Unconformity.

Permian.—Subsidence and deposition of Upper Marine Series. Present Jenolan Plateau just below sea. Formation of Coal Measure swamps. Deposition of Upper Coal Measures. Continued subsidence.

Triassic.—Deposition of Narrabeen and Hawkesbury beds conformable with Permian. Deposition of Wianamatta Shale to east. Since the close of Triassic, dominant movement here is of uplift.

Cretaceous.—*Uplift and Peneplanation (?). (Sussmilch).

Tertiary (Lower and Middle).—Formation of peneplain. Old rivers, since obliterated by basalts, formed.
*Slight subsidence and deposition of river leads.
Slight uplift and basalt flows (Older Basalt).

Tertiary (Upper) (Physiographic Record).—Erosion. Outpouring of the Newer Basalts (e.g. Robertson).
Formation of great peneplain. Present plateau surface.
Cox-Wollondilly systems take form.
Slight uplift. Valleys of Wentworth Falls type.

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* Signifies no reliable evidence in this area.

Post-Tertiary?—Uplift to the north. Formation of old Blue Mountain Anticline.
Post-Tertiary.—General uplift to south and west. Kowmung Warp and Jenolan Dome.
Hartley fault and Mulgoa-Kurrajong "Step".
Recent.—Canyon Cycle. Erosion of great canyons still proceeding.

b. Stream History.

Upper Tertiary.—Upper Wollondilly-Kowmung-Cox formed. Late mature valleys gave meandering courses.
Eastern streams (Nattai, etc.) flow northwards.
Blue Mt. Anticline.—Kowmung-Kanimbla-Wallerawang Valley cut in fold.
Formation of consequent streams—Lower Cox-Wollondilly, Warragamba and Grose. These eroded deep gorges.
Older gravels, Piper's Flat (?).
Kowmung Warp.—Capture of Upper Wollondilly by present Lower Wollondilly.
Capture of Middle Cox and Kowmung by present Lower Cox.
Reversal of Cox in Kanimbla Valley.
Capture of Upper Solitary Creek by Fish River.
Hartley Fault.—Cox forms canyons above Hartley.
Modern Piper's Flat formed.
Slight depression near Wallerawang. Upward movement towards Mt. Lambie.
Solitary Creek threatened with capture.

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EXPLANATION OF PLATES XIX-XX.

Plate xix.

1. Piper's Flat. View from the Main Divide showing the asymmetric valley; the modern silt flats; and the site of older gravels in middle distance.
2. Silt Flats, Blackheath Glen, Megalong Valley. Note the sharp rise of the talus slopes from the level plain.

Plate xx.

1. Walls of Green Wattle Creek. The flat in the foreground at 400 feet contains rounded pebbles. The straight walls are unbroken for some miles.
2. View up Burragorang Valley. Wollondilly on right and Nattai on left. The valley is approaching maturity. Note the peak residuals on the edge of the cliffs. These are arranged along north-south lines.